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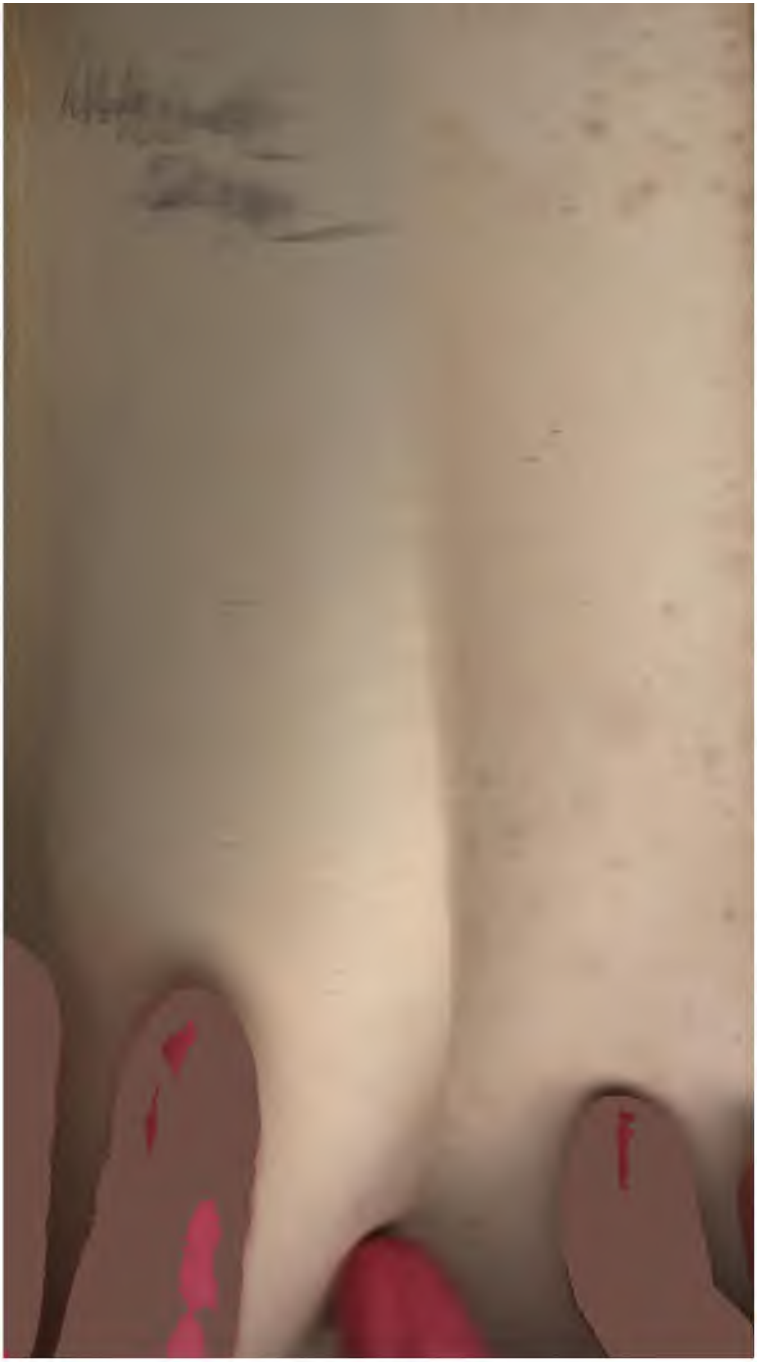

WATT.

Engraved by H.Adlard from a Drawing by H.Corbould, taken with the permission of James Watt, Esq.

FROM THE STATUE BY CHANTREY.

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Edw. Hare. Esqr.
1828.

POPULAR LECTURES
on the
Steam Engine.

BY THE

REV. DIONYSIUS LARDNER, LL.D.

Professor of Natural Philosophy & Astronomy
in the
University of London. F.R.S. M.R.I.A.
&c. &c.

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POPULAR LECTURES

ON

THE STEAM ENGINE,

IN WHICH

ITS CONSTRUCTION AND OPERATION

ARE FAMILIARLY EXPLAINED;

WITH

AN HISTORICAL SKETCH

OF ITS

INVENTION AND PROGRESSIVE IMPROVEMENT.

BY THE REV. DIONYSIUS LARDNER, LL.D.

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PREFACE.

THERE are two classes of persons whose attention may be attracted by a treatise on such a subject as the Steam-Engine. One consists of those who, by trade or profession, are interested in mechanical science, and who therefore seek information on the subject of which it treats, as a matter of necessity, and wish to acquire it in a manner and to an extent which may be practically available in their avocations. The other and more numerous class, is that part of the public in general, who, impelled by choice rather than necessity, think the interest of the subject itself, and the pleasure derivable from the instances of ingenuity which it unfolds, motives sufficiently strong

to induce them to undertake the study of it. It is for the use of this latter class principally that the following lectures are designed.

To this class of readers the Steam-Engine is a subject which, if properly treated of, must present strong and peculiar attractions. Whether we consider the history of its invention as to time and place, the effects which it has produced, or the means by which it has caused these effects, we find every thing to gratify our national pride, stimulate our curiosity, excite our wonder, and command our admiration. The invention and progressive improvement of this extraordinary machine, is the work of our own time and our own country; it has been produced and brought to perfection almost within the last century, and is the exclusive offspring of British Genius fostered and supported by British capital. To enumerate the effects of this invention, would be to count every comfort and luxury of life. It has increased the sum of human happiness, not only by calling new pleasures into existence, but by

so cheapening former enjoyments as to render them attainable by those who before never could have hoped to share them. Nor are its effects confined to England alone; they extend over the whole civilized world; and the savage tribes of America, Asia, and Africa, must ere long feel the benefits, remote or immediate, of this all-powerful agent.

If the effect which this machine has had on commerce and the wealth of nations raise our astonishment, the means by which this effect has been produced, will not less excite our admiration. The history of the Steam-Engine presents a series of contrivances, which for exquisite and refined ingenuity, stand without a parallel in the annals of human invention. These admirable contrivances, unlike other results of scientific investigation, have also this peculiarity, that to understand and appreciate their excellence, requires no previous or subsidiary knowledge. A simple and clear explanation divested as far as possible of technicalities, and assisted by well-selected diagrams, is all

that is necessary to render the principles of the construction and operation of the Steam-Engine intelligible to a person of plain understanding and moderate information. That the following lectures are adapted to attain this end has been in some degree established by the test of public approbation on their delivery, and to more than this they do not aspire.

The purpose for which these lectures are designed, as already explained, has rendered necessary the omission of many particulars which however interesting and instructive to the practical mechanic or professional engineer, would have little attraction for the general reader. Such are, for example, the scale and proportion of the parts, the nature and strength of the materials, the calculation of power, friction, inertia, &c. Our readers require to be informed of the general principles of the construction and operation of Steam-Engines, rather than of their practical details. For the same reasons we have confined ourselves to the more striking and im-

portant circumstances in the history of the invention and progressive improvement of this machine, excluding many petty disputes which arose from time to time respecting the rights of invention, the interest of which is buried in the graves of their respective claimants.

In the descriptive parts of the work we have been governed by the same considerations. The application of the force of steam to mechanical purposes, has been proposed on various occasions, in various countries, and under a great variety of forms. The list of British patents * alone would furnish an author of common industry and application with matter to swell his book to many times the bulk of this volume. By far the greater number of these projects have however proved abortive. Descriptions of these unsuccessful, though frequently ingenious machines, we have thought it advisable to exclude from our pages, as not possessing sufficient interest

* Containing upwards of 250 patents concerning the application of steam!

for the readers to whose use this volume is dedicated. We have therefore strictly confined our descriptions either to those Steam Engines which have come into general use or to those which form an important link in the chain of invention.

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LECTURES

ON

THE STEAM ENGINE.

LECTURE I.

On the Natural Forces which are engaged in different Modifications of the Steam-Engine.

(1.) Of the various productions designed by nature to supply the wants of man, there are few which are suited to his necessities in the state in which the earth spontaneously offers them. If we except air and water we shall scarcely find another instance: even food itself, in most cases, requires culture and preparation. But if, from the mere necessaries of physical existence, we rise to the demands of civil and social life, to say nothing of luxuries and refinements, we find that every thing which contributes to our convenience requires a previous and extensive expenditure of labour. Nay, in most cases, the objects of our enjoyment derive their entire excellence, not from any

quality originally inherent in the natural substance out of which they have been formed, but from those qualities which that substance has received from human labour and human skill. Hence have arisen *Manufactures.*

In all the changes to which the raw productions of the earth are submitted in order to suit them to our wants, one of the principal agents is *Motion.*

Thus, for example, in the conversion of wool into clothing for our bodies it is necessary that it should be twisted into threads and then woven into cloth. In these changes *motion* is the agent. To convert the raw wool into thread, a continued rotatory motion must be produced, which being properly communicated, the wool assumes the required form. In like manner, as is well known, particular motions must be given to the threads, in order to produce among them that peculiar arrangement which characterises the texture of the web.

In a rude state of society, the motions required in the infant manufactures are probably communicated by the immediate application of the hand. Observation and reflection, however, soon suggest more effectual means of attaining these ends. When we look around us in the natural world, we perceive various motions actually existing there; we see water falling and wind blowing, and the question instantly arises, whether, without having recourse to animal strength, we may not use these motions for our manufacturing purposes? Here, however, a difficulty is presented. We require motion of a particular kind; but wind will not blow nor water fall as we please.

nor as suits our peculiar wants, but according to the fixed laws of nature. We want an *upward* motion; water falls *downward*. We want a circular motion; wind blows in a straight line.

The motions, therefore, which are in actual existence in nature, must be modified, in order to suit our purposes. The means whereby these modifications are produced are called *machines*. A *machine*, therefore, is an instrument interposed between some natural force or motion and the object to which force or motion is desired to be transmitted, and of such construction, that the natural motion is made to produce in that object whatever species of motion it may be required to have.

To give a very obvious example, suppose that a circular or rotatory motion were required to be produced, and that the only natural force at our command were a perpendicular fall of water. A wheel is accordingly provided, furnished with cavities in its rim. The water, in descending, is received into those cavities at one side of the wheel, and being discharged at the lowest point, the cavities ascend empty on the other side. There is thus a load of water always pressing down on one side of the wheel, from which the other side is free, and thus a constant rotation is produced.

In every machine, therefore, the nature and properties of the force from which it derives its motion should be one of the first subjects of consideration. This force, whatever it be, is called the *first mover*.

The first mover used in the steam-engine depends on certain mechanical properties of atmospheric air and of the vapor raised from liquids by heat. A short account of these properties will greatly contribute to the ease with which the action of these machines will be understood. We therefore propose, in the present lecture, to explain the principal properties of air and steam, to which we shall have occasion to allude hereafter.

I. *Of the Mechanical Properties of Air.*

(2.) The ATMOSPHERE is the thin transparent fluid in which we live and move, and which, by respiration, supports animal life. This fluid is apparently so light and attenuated, that it might be at first doubted whether it be really a body at all. It will therefore excite some surprise when we assert not only that it is a body, but also that it is one of considerable *weight*. We shall be able to prove that it presses on every *square inch* * of surface with a weight of about 15lb. avoirdupoise.

(3.) Take a glass tube A B (fig. 2.) more than 32 inches long, open at one end A, and closed at the other end B, and let it be filled with mercury (quick-

* As we shall have frequent occasion to mention this magnitude, it would be well that the reader should be familiar with it. It is a *square*, each side of which is an inch. Such as A B C D. Fig. 1.

silver). Let a glass vessel or cistern C, containing a quantity of mercury, be also provided. Applying the finger at A so as to prevent the mercury in the tube from falling out, let the tube be inverted, and the end, stopped by the finger, plunged into the mercury in C. When the end of the tube is below the surface of the mercury in C (fig. 3.) let the finger be removed. It will be found that the mercury in the tube will not, as might be expected, fall to the level of the mercury in the cistern C and which it would do were the end B open so as to admit the air into the upper part of the tube. On the other hand the level D of the mercury in the tube will be about 30 inches above the level C of the mercury in the cistern.

(4.) The cause of this effect is that the weight of the atmosphere rests on the surface C of the mercury in the cistern and tends thereby to press it up, or rather to resist its fall, in the tube, and as the fall is not assisted by the weight of the atmosphere on the surface D, (since B is closed) it follows that as much mercury remains suspended in the tube above the level C as the weight of the atmosphere is able to support.

If we suppose the section of the tube to be equal to the magnitude of a square inch, the weight of the column of mercury in the tube above the level C will be exactly equal to the weight of the atmosphere on each square inch of the surface C. The height of the level D above C being about 30 inches and a column of mercury two inches in height and having a base of a square inch, weighing about one pound avoir-

dupois it follows that the weight with which the atmosphere presses on each square inch of a level surface is about 15lbs. avoirdupoise.

An apparatus thus constructed and furnished with a scale to indicate the height of the level D above the level C is the *common barometer*. The difference of these levels is subject to a small variation which indicates a corresponding change in the atmospheric pressure. But we take 30 inches as a standard or average.

(5.) It is an established property of fluids that they press equally in all directions; and air, like every other fluid, participates in this property. Hence it follows, that since the downward pressure or weight of the atmosphere is about 15lbs. on the square inch, the lateral, upward, and oblique pressures are the same. But independently of the general principle, it may be satisfactory to give experimental proof of this.

Let four glass tubes A, B, C, D, (fig. 4.) be constructed of sufficient length, closed at one end A, B, C, D, and open at the other. Let the open ends of three of them be bent as represented in the tubes B, C, D. Being previously filled with mercury, let them all be gently inverted so as to have their closed ends up as here represented. It will be found that the mercury will be sustained in all, * and that the difference of the levels in all will be the same. Thus the mercury is sustained in A by the upward pressure of the atmo-

* This experiment with the tube A requires to be very carefully executed and the tube should be one of small bore.

sphere, in B by its horizontal or lateral pressure, in C by its downward pressure, and in D by its oblique pressure; and as the difference of the levels is the same in all, these pressures are exactly equal.

(6.) In the experiment described in (3) the space B D (fig. 3.) the top of the tube from which the mercury has fallen is perfectly void and empty, containing neither air nor any other fluid: it is called therefore a *vacuum*. If, however, a small quantity of air be introduced into that space it will immediately begin to exert a pressure on D which will cause the surface D to descend, and it will continue so to descend until the column of mercury C D is so far diminished that the weight of the atmosphere is sufficient to sustain it, as well as the pressure exerted upon it by the air in the space B D.

The quantity of mercury which falls from the tube in this case is necessarily an equivalent for the pressure of the air introduced, so that the pressure of this air may be exactly ascertained by allowing about one pound per square inch for every two inches of mercury which has fallen from the tube. The pressure of the air or any other fluid above the mercury in the tube, may at once be ascertained by comparing the height of the mercury in the tube with the height of the barometer; the difference of the heights will always determine the pressure on the surface of the mercury in the tube. This principle will be found of some importance in considering the action of the modern steam-engines.

The air which we have supposed to be introduced

into the upper part of the tube, presses on the surface of the mercury, with a force much greater than its weight. For example, if the space B D (fig. 3.) were filled with atmospheric air, in its ordinary state it would exert a pressure on the surface D equal to the whole pressure of the atmosphere, although its weight might not amount to a single grain. The property in virtue of which the air exerts this pressure is its elasticity, and this force is diminished in precisely the proportion in which the space it occupies is increased.

Thus it is known that atmospheric air in its ordinary state exerts a pressure on the surface of any vessel in which it is confined amounting to about 15lbs. on every square inch. If the capacity of the vessel which contains it be doubled, it immediately expands and fills the double space, but in doing so it loses half its elastic force and presses only with a force of 7½lbs. on every square inch. If the capacity of the vessel had been enlarged five times, the air would still have expanded so as to fill it, but would exert only a fifth part of its first pressure or 3lbs. on every square inch.

This property of losing its elastic force as its volume or bulk is increased, is not peculiar to air. It is common to all elastic fluids, and we accordingly find it in steam; and it is absolutely necessary to take account of it in estimating the effects of that agent.

(7.) There are numerous instances of the effects of these properties of atmospheric air which continually

fall under our observation. If the nozzle and valve-hole of a pair of bellows be stopped, it will require a very considerable force to separate the boards. This effect is produced by the diminished elastic force of the air remaining between the boards upon the least increase of the space within the bellows, while the atmosphere presses with undiminished force on the external surfaces of the boards. If the boards be separated so as to double the space within, the elastic force of the included air will be about 7½lbs. on every square inch, while the pressure on the external surfaces will be 15lbs. on every square inch; consequently it will require as great a force to sustain the boards in such a position, as it would to separate them if each board were forced against the other with a pressure of 7½lbs. on their external surfaces.

When boys apply a piece of moistened leather to a stone, so as to exclude the air from between them, the stone, though it be of considerable weight, may be lifted by a string attached to the leather. The cause of which is the atmospheric pressure, which keeps the leather and the stone in close contact.

I. *Of the Mechanical Properties of Vapor.*

(8.) If we expose our body to the effects of fire, we feel a certain sensation which we call *heat*. The matter, or whatever it be which causes this sensation, is properly called *caloric*. But in familiar discourse, heat and caloric are used indifferently.

Caloric is known to pervade all bodies in nature,

in a greater or lesser degree; and the quantity of it in any substance may be increased or diminished within certain limits. The increase of the quantity of caloric in a body, is in general attended with an increase of its bulk, and the diminution of it with a corresponding diminution of bulk. Thus metals expand or enlarge their dimensions when heated, and contract when cooled. A flaccid bladder containing a small quantity of air, will when heated become quite distended, owing to the expansion of the air contained in it, but will again resume its flaccid appearance when cooled. And the same is true of all substances.

(9.) So universal is this law of expansion, that it has been actually taken as the measure of the *degree* of heat, and is the principle on which *thermometers* are constructed. Some mercury is enclosed in a glass ball, to which a tube is attached, so that when heat is applied to the ball, the expansion of the metal it contains, forces mercury up in the tube, which being applied to a graduated scale, becomes the measure of temperature, by means of the expansion which that temperature produces.

(10.) Expansion or enlargement of dimension is not, however, the only effect which attends increasing the quantity of caloric in a body. In some cases a total change of form is effected by it. If a superabundant quantity of caloric be given to a piece of solid metal, it will be converted into a liquid. The metal in this case is said to be *fused*, and the process is called *fusion*.

So long as the requisite temperature is kept up and caloric supplied in a sufficient quantity, so long will the metal retain its liquid state; but when that supply is withdrawn, and the temperature lowered, it again resumes its solid form.

Again, if from any substance, as water, which is usually in the liquid state, a considerable portion of caloric be withdrawn, and the temperature lowered, it will at length become solid, and will remain so until the caloric be restored, when it will again resume its liquid form.

From these and numerous other similar circumstances we conclude that all the substances in nature which we observe in the solid or the liquid state, are retained in their respective forms by the agency of caloric.

(11.) The reciprocal changes, liquefaction and solidification, are not the only changes of form, in substances which are produced by a change in their temperature. If heat be communicated to a liquid, as water, its first effect will be to raise its temperature and to enlarge its bulk. But after the temperature has been raised to about 212 degrees of the common thermometer, no further accession of heat will be perceived, and the thermometer placed in it will cease to rise. Nevertheless, heat will be communicated to the water, and the vessel which contains it. What then, it may be asked, becomes of this heat? In this case the water will be in a rapid state of evaporation, or of being converted into steam, and all the heat which is communicated to it in addition to what is indicated by the thermometer, is consumed in the

formation of this steam. Hence it appears that under ordinary circumstances,* water cannot maintain its liquidity at a temperature higher than 212°, and that any additional heat beyond what is necessary to give it this temperature, will convert a part of it into steam.

It appears, therefore, that the quantity of caloric in a liquid, being sufficiently increased, it will at length be converted into a vapor, or changed from an inelastic fluid into an elastic one, and will thus totally change its mechanical character by the acquisition of the property of elasticity already described in air (6). On the other hand, if from elastic vapor the heat be abstracted, it will be again restored to its liquid state, it being incapable of existing, under ordinary circumstances, in the vaporous form, at a lower temperature than 212°.

From all these circumstances we infer, that bodies are retained in the several states of solid, liquid and vapor by the agency of heat, and that the same body may be passed successively through these several states, by a proper change in the caloric which is transfused through its dimensions.

(12.) We have stated that when the increase or diminution of temperature does not change the *form* of a body, it changes its dimensions or bulk. This effect is not confined to solids and liquids, but is found still more perceptibly in vapors and all elastic fluids.

* Under particular circumstances water can maintain its liquidity at any temperature, as will appear hereafter.

If a small quantity of air be included in a flaccid bladder tied at the mouth, so as to be air-tight; when the bladder is held before a fire, it will become distended, and have all the appearance of being inflated. The cause of which obviously is the dilatation of the air contained in it, by the increased temperature which it has acquired.

Again, let a tube A B (fig. 5.) open at both ends, have one end passed through the neck of a vessel C D, containing a coloured liquid with common air above it, and let the tube be fixed so as to be air tight in the neck. Upon heating the vessel the warm air above the level C D will begin to expand, and will press on the surface of the coloured liquid, so as to force it up in the tube A B.

(13.) The same elastic fluid, whether it be a gas or a vapor, has always, at the same temperature or density, the same degree of elastic force, but if either the temperature or the density, or both, be increased, the elastic force is also increased. Therefore the elastic force depends conjointly on the temperature and the density.

(14.) All the effects of caloric which we have just described, may be very satisfactorily accounted for by supposing that it is a substance or a cause imparting to the corpuscles of bodies a repulsive force, by which they acquire a tendency to repel each other. But in conjunction with this, it is necessary to attend to another force which is known to exist in nature. There is observable amongst the constituent

particles of every body, a force in virtue of which they have a tendency to cohere and collect themselves together in concrete solid masses. This tendency is called *cohesion*, or the *attraction of cohesion*. This cohesive force in the particles of matter is directly counteracted by the effects of *caloric*. It is supposed by some that caloric is an highly elastic and very subtle fluid, that transfuses itself through the dimensions of all bodies, and by its elastic force tends to separate and force asunder their particles, and to dissolve the union which the *cohesive* force tends to produce. It is however certain, whatever be the nature of caloric, that it gives to the particles a tendency, the very opposite of cohesion, and that the state of a body, whether solid or liquid, must be decided by the relation between the two forces, viz. the cohesive force natural to its particles, and the repulsive force dependent on the caloric which pervades them. If the cohesion of the particles predominate considerably over the repulsive force of the caloric, the state of the body will be *solid;* if however these forces nearly neutralise each other, it will be *liquid.*

As to mutual cohesion, the particles of a liquid may therefore be considered as *nearly* in a state of indifference. We say *nearly*, because in most liquids a slight tendency to cohesion may be perceived. Thus, if two drops of mercury or water be placed on a glass plate near each other, they will immediately unite and form one drop. But in a general way, and merely in a mechanical point of view, we may re-

gard the parts of liquids to be in a state of indifference as to cohesion.

(15.) By tracing up the analogy which we have commenced, on the effects of the cohesive and repulsive forces incident to the particles of bodies, we would be led to conclude, that by increasing the latter until it greatly predominated over the former, the particles of the body would have as strong a tendency to separate from each other, as they have to collect together, when the opposite relation exists between these two forces; and such in fact we find to be the case. If sufficient heat be communicated to a *liquid*, it will be, as we have before stated, converted into *vapor*, the particles of which repel each other, so that it tends to burst any vessel in which it may be confined. Thus, then, we may account for the existence of the gaseous state, or of what is called *elastic fluids*, the cohesive force natural to the particles of the body is not only overcome by the repulsive force introduced by the caloric, but a strong repulsive influence is given to the particles, so that they endeavour to separate from each other, and to expand continually into an increased bulk, if not resisted by an adequate force.

Thus, if water be exposed to heat until it boil, it will be converted gradually into steam. If this steam be enclosed in any vessel, it will tend to burst its sides with a certain elastic force, exactly in the same manner as air would, if similarly confined. But an effect is observed in the conversion of liquids into vapor by heat, which is not perceptible in the

conversion of solids into liquids. We have said that these several states depend on the mutual proportion of the cohesive and repulsive forces of the particles. There is, however, a third force which always assists the cohesion, to be taken into account, and the effects of which are very apparent in vaporization, although not in liquefaction. This force is the *atmospheric pressure* already described. This evidently tends to press together the parts of a body, and, therefore, assists cohesion. Thus if water be placed in a vessel, and have its surface exposed to the atmosphere when the barometer stands at 30 inches, it will sustain a pressure on its surface amounting to 15lbs. on every square inch. This force in addition to cohesion must be overcome by the repulsive effect of the caloric, before vaporization can commence. By reasoning thus we would be led directly to two conclusions: 1°. that if the atmospheric pressure were removed or diminished, liquids would boil with less heat or at a lower temperature: and 2°. that if the pressure on the surface were increased, they will not boil until a proportionably increased heat be given them, or until they attain a much higher temperature. These inferences we accordingly find supported by experience. Under a pressure of 15lbs. on the square inch, i. e. when the barometer is at 30 inches, water boils at the temperature of 212° of the common thermometer. But if water at a lower temperature, suppose 180°, be placed under the receiver of an air-pump, and, by the process of exhaustion, the atmospheric pressure be removed, or very much diminished, the water will boil, although its temperature still

remain at 180° as may be indicated by a thermometer placed in it.

(16.) On the other hand, if a thermometer be inserted air-tight in the lid of a close digester containing water with common atmospheric air above it, when the vessel is heated the air acquires an increased elasticity, and being confined by the cover, presses with increased force on the surface of the water. By observing the thermometer while the vessel is exposed to the action of heat, it will be seen to rise considerably above 212°, suppose to 280°, and would continue so to rise until the strength of the vessel could no longer resist the pressure within it.

(17.) The temperature at which water boils is commonly said to be 212°, which is called *the boiling point* of the thermometer, but strictly speaking this is only true when the barometer stands at 30 inches. If it be lower, water will boil at a lower temperature, because the atmospheric pressure is less, and if it be higher, as at 31, water will not boil until it receive an higher temperature, the pressure being greater.

According as the cohesive forces of the particles of liquids are more or less active, they boil at greater or lesser temperatures. In general the lighter liquids such as *alcohol* and *ether* boil at lower temperatures. These fluids in fact would boil by merely removing the atmospheric pressure as may be proved by placing them under the receiver of an air pump and withdrawing the air. From this we may conclude that

retain the water in the state of vapor, is sufficient to raise the six cubic inches from 32° to 212°.

A cubic foot of steam raised from water at 212° will itself have only the same temperature 212°. We are, therefore, to conclude that all the additional heat which has been given to it in the process of vaporization is engaged in giving it the elastic form, and being insensible to the thermometer is called *latent heat*. From the facts just mentioned, the immense expenditure of heat in the production of steam must be quite apparent.

Since the temperature at which water boils depends on the pressure to which it is submitted, it is manifest that there is no other limit to the temperature of which it is susceptible except that of the mechanical pressure to which we are able to submit it. We shall see hereafter that it is capable of being raised to 600°, 700° or 800°. In fact that it may be rendered *red-hot*.

The temperature of steam may be changed after it assumes the vaporous form. Thus, steam raised from water at 180° may subsequently be raised to 212°. But whether in this case it will have the same pressure as if it had been raised in the first instance from water at 212°, some late experiments, to which we shall hereafter allude, have rendered doubtful.

(21.) As a liquid is converted into vapor by imparting to it a superabundant supply of caloric, so also a vapor may be restored to the liquid state by withdrawing from it a sufficient portion of caloric. If a close vessel be filled with steam, and then a jet of

cold water be forced into it, the water will immediately draw a quantity of heat from the steam,which will be reduced to water, and will fall in that form on the bottom of the vessel. The same property is also manifested by allowing steam to come in contact with any cold surface. Let any body be held before the steaming spout of a tea-kettle and it will presently become wet. This moisture is the steam reconverted into water by losing part of its heat and resting on the body. This reconversion of steam into water by the abstraction of heat is called *condensation.*

By this property, steam is rendered instrumental in the formation of a *vacuum.* By allowing steam to circulate through a vessel, the air may be expelled from it, and its place filled by steam. If the vessel be then closed and cooled, the steam will be reduced to water, and, falling in drops on the bottom and sides of the vessel, the space which it filled will become a *vacuum.* This may be easily established by experiment. Let a long glass tube be provided with a hollow ball at one end, and having the other end open.* Let a small quantity of spirits be poured in at the open end, and placing the glass ball over the flame of a lamp, let the spirits be boiled. After some time the steam will be observed to issue copiously from the open end of the tube which is presented upwards. When this takes place, let the tube be inverted, and its open end plunged in a

* A common glass flask with a long neck will answer the purpose.

called the source of the majestic object which has excited the inquiry.

The mere fact that the steam of boiling water is capable of producing motion must have been observed at a very early period. No one could look at a close vessel of water boiling, and observe the force with which the steam issues from its spout without, at once, perceiving the possibility of producing motion in any light substance exposed to its action. Yet trifling as this circumstance must appear, it has formed the sole foundation for some claims which have been advanced to the invention of the present steam-engine. *

(23.) The use of the *elastic* force of steam, as a first mover in a machine designed for raising water, was first proposed by EDWARD SOMERSET, MARQUESS OF WORCESTER, in a work intitled "a Century of Inventions," published in the year 1683. The following is the description which is given in that work of the contrivance:

"I have invented an admirable and forcible way to draw up water by fire; not by drawing or sucking it upwards, for that must be, as the philosopher terms it, *intra sphæram activitatis*, which is but at such a distance. But this way hath no bounder if the vessel be strong enough. For I have taken a piece of whole cannon whereof the end was burst, and filled it three quarters full of water, stopping and

* The invention has been claimed for Bianca, an Italian philosopher, who proposed turning the vanes of a mill by a steaming kettle.

screwing up the broken end, as also the touch-hole and making a constant fire under it; within twenty four hours, it burst and made a great crack. So that, having a way to make my vessels so that they are strengthened by the force within them, and the one to fill after the other; I have seen the water run like a constant stream forty feet high. One vessel of water rarefied by fire driveth up forty of cold water, and a man that tends the work has but to turn two cocks; that one vessel of water being consumed another begins to force and refill with cold water and so successively; the fire being tended and kept constant, which the self same person may likewise abundantly perform in the interim between turning the said cocks."

The Marquess states that these experiments were made about 1663. We have, however, no evidence, except his own statement, that he ever constructed the machine or made the experiments above described; and for this reason, some writers on the subject have denied him any share in the discovery of the steam-engine, while others, falling into the opposite extreme give him the entire honor of being its first inventor.

Whether the Marquess of Worcester ever tried these experiments or constructed the machine he alludes to is, we conceive, a matter of perfect and absolute indifference as to the share to which he may be considered to be intitled in the invention of the steam-engine. It is quite clear that, in the passage we have quoted, he distinctly points out the pressure arising from the elastic force of steam as a mechanical agent. He gives an instance of the possibility of

applying it to elevate water, and mentions the advantage which, in this respect, it possesses over the atmospheric pressure, viz. that the latter has a limit, not being capable of supporting more than about 34 feet of water, while the pressure of steam has no other limit than the strength of the vessels which contain it. Had he merely stated these things, without alleging, as he does, that he had actually tried the experiment, he would, we conceive, have an undeniable claim to the merit of having first suggested the elastic force of steam as a mechanical agent of a power almost unlimited, and beyond this, even had he made his experiment publicly, his claim could not be admitted; for it is certain that no engine constructed in the manner to which he alludes, could be rendered extensively useful as a machine even for raising water, as we shall see hereafter.

(24.) No further discovery in the mechanical application of steam, appears to have been made until about the year 1698, when the method of producing a vacuum by the condensation of steam (described in 21) was discovered by Captain SAVERY, who, combining this with the application of the elastic force suggested by the Marquess of Worcester, constructed an engine for raising water, for which he was granted a patent.

Savery states that his discovery of the condensing principle arose from the following circumstance. Having drunk a flask of Florence at a tavern, he called for a bason of water to wash his hands, and flung the empty flask on the fire. A small quantity

of wine which remained in the flask began to boil, and steam issued from its mouth. It occurred to him, to try what effect would be produced by inverting the flask and plunging its mouth in the cold water. Putting on a thick glove to defend his hand from the heat, he did so, and immediately the water in the bason rushed up into the flask and filled it. (See (21)).

This circumstance suggested to Savery the possibility of giving effect to the atmospheric pressure, by creating a vacuum in this manner. If, instead of exhausting the barrel of a pump by the usual laborious method of a piston and sucker, it were exhausted by first filling it with steam, and then condensing the same steam, the atmospheric pressure would force the water in the well up into the pump-barrel, and into any vessel connected with it, provided that vessel were not more than 34 feet above the level of the water in the pump-well. Savery also plainly saw, that this water might be forced to a still greater elevation by using the elastic force of steam upon the Marquess of Worcester's principle, and that this very steam would serve by its subsequent condensation to repeat the vacuum, and draw up more water. On these principles Savery constructed his steam-engine.

(25.) In this, and indeed every steam-engine, there are two parts; 1°. that which is employed in generating the steam (the *boiler*); and 2°. that in which the steam is applied as a moving power, (the *working apparatus*). We shall first describe the former apparatus in Savery's engine.

The sections of two strong boilers D E, are repre-

sented in fig. 7, D the greater and E the less. The tubes T and T′ communicate with the working apparatus which we shall presently describe. A thin plate of metal R is applied closely to the top of the principal boiler D turning on a centre C, so that by moving a lever applied to the axis C on the outside of the top, the sliding plate R can be brought from the mouth of the one tube to the mouth of the other alternately. This sliding valve is called the *regulator*, since it is by it that the communications between the boiler and two steam vessels (hereafter described,) are alternately opened and closed, the lever which effects this being constantly wrought by the hand of the attendant.

Two *gauge pipes* are represented at G, G′, the use of which is to determine the depth of water in the boiler. One G has its lower aperture a little above the proper depth, and the other G′ a little below it. Cocks are attached to the upper ends G, G′, which can be opened or closed at pleasure. The steam collected in the top of the boiler pressing on the surface of the water forces it up in the tubes G, G′, if their lower ends be immersed. Upon opening the cocks G, G′, if water be forced from both, there is too much water in the boiler, since the mouth of G is *below* its level. If steam issue from both there is too little water in the boiler, since the mouth of G′ is *above* its level. But if steam issue from G and water from G′ the water in the boiler is at its proper level. This ingenious contrivance for determining the level of the water in the boiler is the invention of Savery, and is used in many instances at the present day.

The mouth of G should be at a level of a little less than one-third of the whole depth, and the mouth of G′ at a level a little lower than one third; for it is requisite that about two thirds of the boiler should be kept filled. The tube I forms a communication between the principal boiler D and the subsidiary or feeding boiler E descending nearly to the bottom of it. This communication can be opened and closed at pleasure by the cock K. A gauge pipe is inserted similar to G, G′ but extending nearly to the bottom. From this boiler a tube F extends which is continued to a cistern C (fig. 8.) and a cock is placed at M which, when opened, allows the water from the cistern to flow into the feeding boiler E, and which is closed when that boiler is filled. The manner in which this cistern is supplied will be described hereafter.

Let us now suppose that the principal boiler is filled to the level between the gauge pipes, and that the subsidiary boiler is nearly full of water, the cock K and the gauge cocks G G′ being all closed. The fire being lighted beneath D and the water boiled, steam is produced and is transmitted through the tubes T T′, to the working apparatus. When evaporation has reduced the water in D below the level of G′ it will be necessary to replenish the boiler D. This is effected thus. A fire being lighted beneath the feeding boiler E, steam is produced in it above the surface of the water, which having no escape presses on the surface so as to force it up in the pipe I. The cock K being then opened, the boiling water is forced into the principal boiler D, into which it is allowed to flow until water issues from the gauge cock G′. When this

takes place, the cock K is closed, and the fire removed from E until the great boiler again wants replenishing. When the feeding boiler E has been exhausted, it is replenished from the cistern C (fig. 8.) through the pipe F by opening the cock M.

(26.) We shall now describe the working apparatus in which the steam is used as a moving power.

Let V V′ (fig. 8.) be two steam-vessels communicating by the tubes T T′ (marked by the same letters in fig. 7.) with the greater boiler D.

Let S be a pipe, called the *suction pipe*, descending into the well or reservoir from which the water is to be raised, and communicating with each of the steam-vessels through tubes D D′ by valves A A′ which open upwards. Let F be a pipe continued from the level of the engine of whatever higher level it is intended to elevate the water. The steam vessels V V′ communicate with the *force pipe* F by valves B B′ which open upward, through the tubes E E′. Over the steam vessels and on the force pipe is placed a small cistern C already mentioned which is kept filled with cold water from the pipe and from the bottom of which proceeds a pipe terminated with a cock G. This is called the *condensing pipe* and can be brought alternately over each steam-vessel. From this cistern another pipe communicates with the feeding boiler (fig. 7.), by the cock M.*

The communication of the pipes T T′ with the

* This pipe in fig. 9. is represented as proceeding from the force-pipe above the cistern C.

boiler can be opened and closed, alternately, by the regulator B, (fig. 7.) already described.

Now suppose the steam-vessels and tubes to be all filled with common atmospheric air and that the regulator be placed so that the communication between the tube T and the boiler be opened, the communication between the other tube T′ and the boiler being closed. Steam will flow into V through T. At first, while the vessel V is cold, the steam will be condensed and will fall in drops of water on the bottom and sides of the vessel. The continued supply of steam from the boiler will at length impart such a degree of heat to the vessel V that it will cease to condense it. Mixed with the heated air contained in the vessel V, it will have an elastic force greater than the atmospheric pressure, and will therefore force open the valve B through which a mixture of air and steam will be driven until all the air in the vessel V will have passed out, and it will contain nothing but the pure vapor of water.

When this has taken place, suppose the regulator be moved so as to close the communication between the tube T and the boiler, and to stop the further supply of steam to the vessel V; and at the same time let the condensing pipe G be brought over the vessel V and the cock opened so as to let a stream of cold water flow upon it. This will cool the vessel, and the steam with which it is filled will be condensed and fall in a few drops of water, leaving the interior of the vessel a vacuum. The valve B will be kept closed by the atmospheric pressure. But the elastic force of the air between the valve A and the surface

of the water in the well, or reservoir, will open A so that a part of this air will rush in (21) and occupy the vessel V. The air in the suction pipe S, being thus allowed an increased space, will be proportionably diminished in its elastic force (6) and its pressure will no longer balance that of the atmosphere acting on the external surface L * of the water in the reservoir. This pressure will, therefore, force water up in the tube S until its weight, together with the elastic force of the air above it, balances the atmospheric pressure on L (4). When this has taken place, the water will cease to ascend.

Let us now suppose that, by shifting the regulator, the communication is opened between T and the boiler, so that steam flows again into V. The condensing cock G being removed, the vessel will be again heated as before, the air expelled, and its place filled by the steam. The condensing pipe being again allowed to play upon the vessel V, and the further supply of steam being stopped, a vacuum will be produced in V, and the atmospheric pressure on L will force the water through the valve A into the vessel V which it will nearly fill, a small quantity of air however remaining above it.

Thus far the mechanical agency employed in elevating the water is the atmospheric pressure; and the power of steam is no further employed than in the production of a vacuum. But, in order to continue the elevation of the water through the force pipe F, above the level of the steam-vessel, it will be necessary to use the elastic pressure of the steam. The

* Not in the diagram.

vessel V is now nearly filled by the water which has been forced into it by the atmosphere. Let us suppose that the regulator being shifted again, the communication between the tube T and the boiler is opened, the condensing cock removed, and that steam flows into V. At first coming in contact with the cold surface of the water and that of the vessel, it is condensed; but the vessel is soon heated, and the water formed by the condensed steam collects in a sheet or film on the surface of the water in V, so as to form a surface as hot as boiling water.* The steam then being no longer condensed, presses on the surface of the water with its elastic force and when that pressure becomes greater than the atmospheric pressure, the valve B is forced open and the water, issuing through it, passes through E into the force pipe F and this is continued until the steam has forced all the water from V, and occupies its place.

The further admission of steam through T is once more stopped by moving the regulator, and the condensing pipe being again allowed to play on V, so as to condense the steam which fills it, produces a vacuum. Into this vacuum, as before, the atmospheric pressure on L will force the water and fill the vessel V. The condensing pipe being then closed and steam admitted through T, the water in V will be forced by its pressure through the valve B and tube E into F, and so the process is continued.

We have not yet noticed the other steam vessel V′ which, as far as we have described, would have re-

* Hot water being lighter than cold, floats on the surface.

mained filled with common atmospheric air, the pressure of which, on the valve A′, would have prevented the water raised in the suction pipe s from passing through it. However, this is not the case; for, during the entire process which has been described in v, similar effects have been proceeding in v′, to which I have only omitted to solicit your notice, to avoid the confusion which the two processes might produce. It will be remembered, that after the steam, in the first instance, having flowed from the boiler through T, has blown the air out of v through B, the communication between T and the boiler is closed. Now the same motion of the regulator which closes this, opens the communication between T′ and the boiler; for the sliding plate R (fig. 7.) is moved from the one tube to the other, and at the same time, as we have already stated the condensing pipe is brought to play on v. While, therefore, a vacuum is being formed in v by condensation, the steam, flowing through T′, blows out the air through B′, as already described in the other vessel v; and, while the air in s is rushing up through A into v followed by the water raised in s by the atmospheric pressure on L, the vessel v′ is being filled with steam, and the air is completely expelled from it.

The communication between T and the boiler is now again opened, and the communication between T′ and the boiler closed by moving the regulator R (fig. 7.) from the tube T to T′; at the same time the condensing pipe is removed from over v and brought to play upon v′. While the steam once more expels the air from v through B, a vacuum is formed by condensation in v′, into which the water in s rushes

through the valve A′. In the mean time v is again filled with steam. The communication between T and the boiler is now closed, and that between T′ and the boiler is opened, and the condensing pipe removed from v′ and brought to play on v. While th steam from the boiler forces the water in v′ through B′ into the forcepipe F, a vacuum is being produced in v into which water is raised by the atmospheric pressure at L.

Thus each of the vessels v v′ is alternately filled from s and the water thence forced into F. The same steam which forces the water from the vessels into F, having done its duty, is condensed, and brings up the water from I by giving effect to the atmospheric pressure.

During this process, two alternate motions or adjustments must be constantly made; the communication between T and the boiler must be opened, and that between T′ and the boiler closed, which is done by one motion of the regulator. The condensing pipe at the same time must be brought from v to play on v′ which is done by the lever placed upon it. Again the communication between T and the boiler is to be opened, and that between T and the boiler closed; this is done by moving back the regulator. The condensing pipe is brought from v′ to v by moving back the other lever, and so on alternately.

(27.) Such are the construction and operation of the steam-engine, contrived by Captain Savery in the year 1698, and which is the first instance in which

we have satisfactory evidence of the use of steam, as a moving power, on any scale worthy of mention. For the clearness and convenience of description, I have made some slight and otherwise unimportant changes in the position of the parts. * A perspective view of this engine is presented in fig. 9. The different parts already described will easily be recognized, being marked with the same letters as in fig. 6, 7.

(28.) Savery's share in the invention of the steam-engine is easily assigned. It will be seen in a future lecture that the motion, in modern steam-engines, is produced by placing a piston in a cylinder, and producing a vacuum on one side of the piston by the condensation of steam, while the elastic pressure of steam is introduced at the other side. Thus, while the pressure on the one side of the piston is effected by the direct mechanical agency of steam, discovered by Lord Worcester, that pressure is rendered efficacious by the vacuum generated on the other side by the method of condensing the steam, discovered by Captain Savery. Thus, the whole honor of the discovery of those properties of steam, on which its power as a first mover depends, is to be equally shared

* In the diagrams used for explaining the principles and operation of machines, I have found it contribute much to the clearness of the description to adopt an arrangement of parts somewhat different from that of the real machine. When once the nature and principles on which the machine acts are well understood. The reader will find no difficulty in transferring every part to its proper place, which is represented in the perspective drawings.

between these two distinguished individuals. This, however, is the extent of their claims. All the beautiful contrivances by which this vast power is applied, regulated and economised, are the result of the ingenuity of their successors, and the engine suggested by Worcester and that constructed by Savery will be found to have scarcely any thing in common with those of the present day, except their *first mover.*

LECTURE III.

Defects of Savery's Engine — Newcomen and Cawley — The Atmospheric Engine — Condensation by jet discovered — Operation of the Engine — Humphrey Potter's Invention to make the Engine work itself.

(29.) In order duly to appreciate the value of improvements, it is necessary first to perceive the defects which these improvements are designed to remove. Savery's steam-engine, described in the last lecture, considering how little was known of the value and properties of steam, and how low the general standard of mechanical knowledge was in his day, is certainly highly creditable to his genius. Nevertheless it had very considerable defects, and was finally found to be inefficient for the most important purposes to which he proposed applying it.

At the time of this invention, the mines in England had greatly increased in depth, and the process of draining them had become both expensive and difficult; so much so, that it was found in many instances that their produce did not cover the cost of working them. The drainage of these mines was the great object Savery proposed to effect by his steam-engine. Its powers, however, were not found, ultimately, equal to his expectation.

It has been already stated, that the pressure of the

atmosphere amounts to about 15lbs. (4) on every square inch. Now, a column of water, whose base is one square inch, and whose height is 34 feet, weighs about 15lbs. If we suppose that a perfect vacuum were produced in the steam-vessels v v′ (fig. 8.) by condensation, the atmospheric pressure on L would fail to force up the water, if the height of the top of these vessels exceeded 34 feet. It is plain, therefore, from this reasoning, that the engine cannot be more than 34 feet above the water which it is intended to elevate. But in fact it cannot be even so much; for the vacuum produced in the steam-vessels v v′ is never perfect. Water, when not submitted to the pressure of the atmosphere, will vaporize at a very low temperature (17); and it was found, that a vapour possessing a considerable elasticity would, notwithstanding the condensation, remain in the vessels v v′ and the pipe s, and would oppose the ascent of the water. In consequence of this, it was found that the engine could never be placed with practical advantage at a greater height than 26 feet above the level of the water to be raised.

(30). When the water is elevated to the engine, and the steam-vessels filled, if steam be introduced above the water in v, it must first balance the atmospheric pressure, before it can force the water through the valve B. Here, then, is a mechanical pressure of 15lbs. per square inch expended, without any water raised by it. If steam of twice that elastic force be used, it will elevate a column in F of 34 feet in height; and if steam of treble the force be used, it

will raise a column of 68 feet high, which, added to 26 feet raised by the atmosphere, gives a total lift of 94 feet.

In effecting this, steam of a pressure equal to three times that of the atmosphere, acts on the under surface of the vessels v v'. One third of this bursting pressure is balanced by the pressure of the atmosphere on the external surface of the vessels; but an effective pressure of 30lbs. per square inch still remains, tending to burst the vessels. It was found, that the apparatus could not be constructed to bear more than this with safety; and, therefore, in practice the lift of such an engine was limited to about 90 perpendicular feet. In order to raise the water from bottom of the mine by these engines, therefore, it was necessary to place one at every 90 feet of the depth; so that the water raised by one through the first 90 feet, should be received in a reservoir, from which it was to be elevated the next 90 feet by another, and so on.

Besides this, it was found sufficient strength could not be given to those engines, if constructed upon a large scale. They were, therefore, necessarily very limited in their dimensions, and were incapable of raising the water with sufficient speed. Hence arose a necessity for several engines at each level, which greatly enhanced the expense.

(31.) These, however, were not the only defects of Savery's engines. The consumption of fuel was enormous, the proportion of heat wasted being much more than what was used in either forcing up the

water, or producing a *vacuum*. This will be very easily understood by attending to the process of working the engine described in the last lecture.

When the steam is first introduced from the boiler into the steam-vessels v v′, preparatory to the formation of a vacuum, it is necessary that it should heat these vessels up to the temperature of the steam itself, viz. 212°; for until then the steam will be condensed the moment it enters the vessel by the cool surface. All this heat, therefore, spent in raising the temperature of the steam-vessels is wanted. Again, when the water has ascended and filled the vessels v v′, and steam is introduced to force this water through B B′ into F, it is immediately condensed by the cold surface in v v′, and does not begin to act until a quantity of hot water, formed by condensed steam, is collected on the surface of the cold water which fills the vessel v v′. Hence another source of the waste of heat.

When the steam begins to act upon the surface of the water in v v′, and to force it down, the cold surface of the vessel is gradually exposed to the steam, and must be heated while the steam continues its action; and when the water has been forced out of the vessel, the vessel itself has been heated to the temperature of the steam which fills it, all which heat is dissipated by the subsequent process of condensation. It must thus be evident that the steam used in forcing up the water in F, and in producing a vacuum, bears a very small proportion indeed to what is consumed in heating the apparatus after every condensation.

There is also another circumstance which increases

the consumption of fuel. When the water is to be forced through B, not only against the atmospheric pressure, but against a column of 68 feet of water, steam is required of a pressure of 45lbs. on the square inch. Consequently the water in the boiler must be boiling under this pressure. That this should take place, it is necessary that the water should be raised to a temperature considerably above 212° (17), even so high as 267°; and thus an increased heat must be given to the boiler. Independently of the other defects, this intense heat weakened and gradually destroyed the apparatus.

Besides the drainage of mines, Savery proposed to apply his steam-engine to a variety of other purposes; such as supplying cities with water, forming ornamental water-works in pleasure grounds, turning mills, &c.

Savery was the first who suggested the method of expressing the power of an engine with reference to that of horses. In this comparison, however, he supposed each horse to work but 8 hours a day, while the engine works for 24 hours. This method of expressing the power of steam-engines will be explained hereafter.

(32.) The failure of the engines proposed by Captain Savery in the great work of drainage, from the causes which have been just mentioned; and the increasing necessity for effecting this, arising from the circumstance of the large properties which became every year unproductive by it, stimulated the ingenuity of mechanics to contrive some means of ren-

dering those powers of steam exhibited in Savery's engine practically available. Among others, NEWCOMEN and CAWLEY, two tradesmen of the town of Dartmouth, turned their attention to this enquiry.

Newcomen appears to have resumed the old method of raising the water from the mines by ordinary pumps, but conceived the idea of working these pumps by some moving power less expensive than that of horses. The means whereby he proposed effecting this, was by connecting the end of the pump-rod D (fig. 10.), by a chain, with the arch head A of a working beam A B, playing on an axis C. The other arch head B of this beam was connected by a chain with the rod E of a solid piston P, which moved air-tight in a cylinder F. If a vacuum be created beneath the piston P, the atmospheric pressure acting upon it will press it down with a force of 15lbs. per square inch; and the end A of the beam being thus raised, the pump-rod D will be drawn up. If a pressure equivalent to the atmosphere be then introduced below the piston, so as to neutralize the downward pressure, the piston will be in a state of indifference as to rising or falling; and if in this case the rod D be made heavier than the piston, and its rod so as to overcome the friction, &c. it will descend, and elevate the piston again to the top of the cylinder. The vacuum being again produced, another descent of the piston, and consequent elevation of the pump-rod, will take place; and so the process may be continued.

Such was Newcomen's first conception of the *atmospheric engine;* and the contrivance had much, even at the first view, to recommend it. The power of such

a machine would depend entirely on the magnitude of the piston; and being independent of an highly elastic steam, would not expose the materials to the destructive heat which was necessary for working Savery's engine. Supposing a perfect vacuum to be produced under the piston in the cylinder, an effective downward pressure would be obtained, amounting to 15 times as many pounds as there are square inches in the section of the piston.* Thus, if the base of the piston were 100 square inches, a pressure equal to 1500lbs. would be obtained.

(33.) In order to accomplish this design, two things were necessary: 1°. To make a speedy and effectual vacuum below the piston in the descent; and 2°. to contrive a counterpoise for the atmosphere in the ascent.

The condensing principle of Savery immediately presented itself as the most effectual means of accomplishing the former; and the elastic force of the

* As the calculation of the power of an engine depends on the number of square inches in the section of the piston, it may be useful to give a rule for computing the number of square inches in a circle. The following rule will always give the dimensions with sufficient accuracy: *Multiply the number of inches in the diameter by itself; divide the product by* 14, *and multiply the quotient thus obtained by* 11, *and the result will be the number of square inches in the circle.* Thus if there be 12 inches in the diameter, this multiplied by itself gives 144, which divided by 14 gives 10$\frac{2}{7}$, which multiplied by 11 gives 115, neglecting fractions. There are, therefore, 115 square inches in a circle whose diameter is 12 inches.

steam introduced to be condensed, an obvious method of effecting the latter. Nothing now remained to carry the design into execution, but the contrivance of mechanism for the alternate introduction and condensation of the steam; and Newcomen and Cawley were accordingly granted a patent in 1707, in which Savery was united, in consequence of his principle of condensation being vitally necessary to the projected machine. We shall now describe the *atmospheric engine*, as first constructed by Newcomen:

The boiler K is placed over a furnace I, the flue of which winds round it, so as to communicate heat to every part of the bottom of it. In the top, which is hemispherical, two gauge-pipes G G′ are placed, as in Savery's engine, and a *puppet valve* V, which opens outward, and is loaded at one pound per square inch; so that when the steam produced in the boiler exceeds the pressure of the atmosphere by more than one pound on the square inch, the valve V is lifted, and the steam escapes through it, and continues to escape until its pressure is sufficiently diminished, when the valve V again falls into its seat.

The great steam-tube is represented at S, which conducts steam from the boiler to the cylinder, and a feeding pipe T furnished with a cock, which is opened and closed at pleasure, proceeds from a cistern L to the boiler. By this pipe the boiler may be replenished from the cistern, when the gauge cock G′ indicates that the level has fallen below it. The cistern L is supplied with hot water by means which we shall presently explain.

(34.) In order to understand the mechanism necessary to work the piston, let us consider how the supply and condensation of steam must be regulated. When the piston has been forced to the bottom of the cylinder by the atmospheric pressure acting against a vacuum, in order to balance that pressure, and enable it to be drawn up by the weight of the pump-rod, it is necessary to introduce steam from the boiler. For this purpose, therefore, the steam-pipe s enters the bottom of the cylinder. The pressure of the steam being thus introduced, the piston ascends; and when it has reached the top of the cylinder, the space below it is completely filled with steam. It then becomes necessary to condense this steam, in order to produce a vacuum. To accomplish this the further supply of steam must be cut off, which is done by a sliding plate R, similar to the *regulator* in Savery's engine, and which is moved over the aperture in the bottom of the cylinder by means of a lever as already described. The supply of steam from the boiler being thus suspended, the affusion of cold water on the external surface of the cylinder becomes necessary to condense the steam within it. This was done by enclosing the cylinder within another, leaving a space between them.* Into this space cold water is allowed to flow from a cock M placed over it, which is supplied by a pipe from the cistern N. This cistern is supplied with water by a pump O, which is worked by the engine itself, from the beam above it.

* The external cylinder is not represented in the diagram.

The cold water supplied from M, having filled the interstice between the two cylinders, abstracts the heat from the inner one; and condensing the steam, produces a vacuum into which the piston is immediately forced by the atmospheric pressure. Preparatory to the next descent, the water which thus fills the space between the cylinders, and which is warmed by the heat it has abstracted from the steam, must be discharged, in order to give room for a fresh supply of cold water from M. An aperture, furnished with a cock, is accordingly provided in the bottom of the cylinder, through which the water is discharged into the cistern L; and being warm, is better adapted for the supply of the boiler through T, as already mentioned.

The regulator R being now again opened, steam is admitted below the piston, which, as before, ascends, and the descent is again accomplished by condensation; and so the process may be continued.

Upon cooling the inner cylinder, the condensed steam, being reduced to water, will collect in the bottom, and resist the descent of the piston. It is, therefore, necessary to provide an exit for it, which is done by a valve opening *outwards* into a tube which leads to the feeding cistern L, into which the condensed steam is driven.

That the piston should continue to be air-tight, it was necessary to keep a constant supply of water over it; this was done by a cock similar to M, which allowed water to flow from the pipe M on the piston.

(35.) Soon after the first construction of these engines, an accidental circumstance suggested to Newcomen, a much better method of condensation than the affusion of cold water on the external surface of the cylinder. An engine was observed to work several strokes with unusual rapidity, and without the regular supply of the condensing water. Upon examining the piston, a hole was found in it through which the water, which was poured on to keep it air-tight, flowed, and instantly condensed the steam under it.

On this suggestion Newcomen abandoned the external cylinder, and introduced a pipe H furnished with a cock Q into the bottom of the cylinder, so that, on turning the cock the pressure of the water, in the pipe H from the level of the water in the cistern N, would force the water to rise in a jet into the cylinder, and would instantly condense the steam. This method of condensing by a jet formed a very important improvement in the engine, and is the method still used.

(36.) Having taken a general view of the parts of the atmospheric engine, let us now consider more particularly its operation.

When the engine is not working the weight of the pump-rod D draws down the beam A, and draws the piston to the top of the cylinder where it rests. Let us suppose all the cocks and valves closed, and the boiler filled to the proper depth. The fire being lighted beneath it, the water is boiled until the steam acquires sufficient force to lift the valve V.

When this takes place the engine may be started. For this purpose the regulating valve R is opened. The steam rushes in and is first condensed by the cold cylinder. After a short time the cylinder acquires the temperature of the steam, which then ceases to be condensed, and mixes with the air which filled the cylinder. The steam and heated air, having a greater force than the atmospheric pressure, will open a valve placed at the end of a small tube in the bottom of the cylinder, and which opens outwards. From this (which is called the *blowing valve**) the steam and air rush in a constant stream until all the air has been expelled, and the cylinder is filled with the pure vapor of water. This process is called *blowing* the engine preparatory to starting it.

When it is about to be started, the engine-man closes the regulator R, and thereby suspends the supply of steam from the boiler. At the same time he opens the *condensing valve* Q ;† and thereby throws up a jet of cold water into the cylinder. This immediately condenses the steam contained in the cylinder and produces the vacuum. (The atmosphere cannot enter the *blowing* valve because it opens *outwards*, so that no air can enter to vitiate the vacuum.) The atmospheric pressure above the piston now takes effect, and forces it down in the cylinder. The descent being completed, the engine-man closes the

* Also called the *snifting* valve from the peculiar noise made by the air, and steam escaping from it.

† Also called the *injection valve*.

condensing valve Q, and opens the regulator R. By this means he stops the play of the jet within the cylinder, and admits the steam from the boiler. The first effect of the steam is to expel the condensing water and condensed steam which are collected in the bottom of the cylinder through a tube containing a valve which opens *outwards* (called the *eduction valve*,) and which leads to the hot cistern L, into which this water is therefore discharged.

When the steam admitted through R ceases to be condensed, it balances the atmospheric pressure above the piston, and thus permits it to be drawn to the top of the cylinder by the weight of the rod D. This ascent of the piston is also assisted by the circumstance of the steam being somewhat stronger than the atmosphere.

When the piston has reached the top, the regulating valve R is closed, and the condensing valve Q opened, and another descent produced as before, and so the process is continued.

The manipulation necessary in working this engine was, therefore, the alternate opening and closing of two valves, the regulating and condensing valves. When the piston reached the top of the cylinder, the former was to be closed, and the latter opened, and, on reaching the bottom, the former was to be opened, and the latter closed.

(37.) From the imperfect attention which even an assiduous attendant could give to the management of these valves, the performance of the engines was very irregular, and the waste of fuel very great, until

a boy named *Humphrey Potter* contrived means of making the engine work its own valves. This contrivance, although made with no other design than the indulgence of an idle disposition, nevertheless constituted a most important step in the progressive improvement of the steam-engine, for by its means, not only the irregularity arising from the negligence of attendants was avoided, but the operation of the engine was doubled, so that one half of the fuel was saved.

Potter attached strings to the levers which worked the valves, and carrying these strings to the working beam, fastened them upon it in such a manner that as the beam ascended and descended, it pulled the strings so as to open and close the proper valves with the most perfect regularity and certainty. This contrivance was afterwards improved upon by an engineer named *Beighton* who attached a straight beam called a *plug frame* to the working beam which carried pins which, in the ascent and descent of the beam, struck the levers attached to the valves, and opened and closed them exactly at the proper moment.

The engine thus improved required no other attendance except to feed the boiler occasionally by the cock T, and to attend the furnace.

LECTURE IV.

Advantages of the Atmospheric Engine over that of Captain Savery. It contained no new Principle — Papin's Engine — Unfounded Claims of the French for the Invention of the Steam-Engine—James Watt — Particulars of his Life. His first Conceptions of the Means of economising Heat. Principle of his projected Improvements.

(38.) CONSIDERED practically, the atmospheric engine described in the last lecture possessed considerable advantages over those of Savery; and even at the present day is not unfrequently used in districts where fuel is very abundant and cheap, its first cost being considerably less than that of a modern engine. The low pressure of the steam which worked them rendered the use of these engines perfectly safe; there being only a bursting pressure of about 1lb. per inch, while in Savery's there was a bursting pressure amounting to 30lbs. The low temperature of the steam used, which did not exceed 216°, did not weaken or destroy the materials; while Savery's engines required steam raised from water at 267°, which in a short time rendered the engine unable to sustain the pressure.

The power of Savery's engines was also very limited, both as to the quantity of water raised, and the height to which it was elevated. (29) On the other

hand, the atmospheric engine had no other limit than the dimensions of the piston. In estimating the power of these engines, however, we cannot allow the full atmospheric pressure as an effective force. The condensing water being mixed with the condensed steam, forms a quantity of hot water in the bottom of the cylinder, which, not being submitted to the atmospheric pressure (17), produces a vapour which resists the descent of the piston. In practice we find that an allowance of at least 3lbs. per square inch should be made for the resistance of this vapour, and 1lb. per square inch for friction, &c.; so that the effective force will be found by subtracting these 4lbs. per square inch from the atmospheric pressure; which, if estimated at 15lbs. leaves an effective working power of about 11lbs. per square inch. This, however, is rather above what is commonly obtained.

Another advantage which this engine has over those of Savery, is the facility with which it might be applied to drive machinery by means of the working beam.

(39.) On the score of invention, Newcomen does not appear to have much claim. The agency of the atmospheric pressure was long known; the formation of a vacuum by the condensation of steam was Savery's discovery; the elastic force of steam used to balance the atmosphere in the ascent, was the discovery of lord Worcester; the construction of the boiler, gauge-pipes, regulator, &c. were similar to those in Savery's engines. The idea of working a

piston in a cylinder by the atmospheric pressure, by forming a vacuum below it, was suggested by Otto Guericke, an ingenious German philosopher, and the inventor of the air-pump. The use of a working-beam could not have been unknown. Nevertheless, very considerable credit must be acknowledged to be due to Newcomen for the judicious combination of all these scattered principles, so as to form the atmospheric engine.

(40.) The patent of Newcomen was granted in 1705; and in 1707, PAPIN, a native of France, and professor of mathematics at *Marpurg*, published a work entitled, "A New Method of raising Water by Fire," in which a steam-engine is described, which would scarcely merit notice here, were it not that it forms the ground on which the French claim the invention of the steam-engine. The publication of Papin's work was nine years after Savery's patent, with which he acknowledges himself acquainted, and two years after Newcomen's. The following is a description of Papin's steam-engine:

An oval boiler, A (fig. 11.), is filled to about two-thirds of its entire capacity with water, through a valve B in the top, which opens upwards, and is kept down by a lever carrying a sliding weight. The pressure on the valve is regulated by moving the weight to or from B, like the common steelyard. This boiler communicates with a cylinder C, by a syphon tube furnished with a stopcock at D. The cylinder C has a valve F in the top, closed by a lever and weight similar to B, and a tube with a stopcock G

opening into the atmosphere. In this cylinder is placed a hollow copper piston H, which moves freely in it, and floats upon the water. Another tube forms a communication between the bottom of this cylinder and the bottom of a close cylindrical vessel I, called the *air-vessel*. In this tube is a valve at K, opening *upwards*, also a pipe terminated in a funnel, and furnished with a valve L, which opens *downwards*. From the lower part of the air-vessel a tube proceeds, furnished also with a stopcock M, and which is continued to whatever height the water is to be raised.

Water being poured into the funnel, passes through the valve L, which opens downwards, and filling the tube, ascends into the cylinder C, carrying the floating piston H on its surface, and maintains the same level in C which it has in the funnel. In this manner the cylinder C may be filled to the level of the top of the funnel. In this process, the cock G should be left open to allow the air in the cylinder to escape as the water rises.

Let us now suppose that, a fire being placed beneath the boiler, steam is being produced. On opening the cock D, and closing G, the steam, flowing through the syphon tube into the top of the cylinder, presses down the floating piston, and forces the water through the lower tube. The passage at L being stopped, since L opens *downwards*, the water forces open the valve K, and passes into the air-vessel I. When the piston H has been forced to the bottom of the cylinder, the cock D is closed, and G is opened, and the steam allowed to escape into the atmosphere. The cylinder is then replenished from the funnel as

ment maker in London. After a short time, finding his health declining, he returned to Scotland, and commenced business on his own account at Glasgow. In 1757 he was appointed mathematical instrument maker to the university of Glasgow, where he resided and carried on his business.

This circumstance produced an acquaintance between him and the celebrated Dr. Robison, then a student in Glasgow, who directed Watt's attention to the steam-engine. In his first experiments he used steam of a high pressure; but found it attended with so much danger of bursting the boiler, and difficulty of keeping the joints tight, and other objections, that he relinquished the enquiry at that time.

(43.) In the winter of 1763, Watt was employed to repair the model of an atmospheric engine, belonging to the natural philosophy class in the university, a circumstance which again turned his attention to the subject of the steam-engine. He found the consumption of steam in working this model so great, that he concluded that the quantity wasted must have had a very large proportion to that spent in working the piston. His first conclusion was, that the material of the cylinder (brass) was too good a conductor of heat, and that much was thereby lost. He made some experiments, accordingly, with wooden cylinders soaked in linseed oil, which, however, he soon laid aside. Further consideration convinced him that a prodigious waste of steam was essential to the very principle of the atmospheric engine. This will be easily understood.

When the steam fills the cylinder so as to balance the atmospheric pressure on the piston, the cylinder must have the same temperature as the steam itself. Now, on introducing the condensing jet, the steam mixed with this water forms a mass of hot water in the bottom of the cylinder. This water, not being under the atmospheric pressure, boils at very low temperatures, and produces a vapour which resists the descent of the piston.

The heat of the cylinder itself assists this process; so that in order to produce a tolerably perfect vacuum under the piston, it was found necessary to introduce so considerable a quantity of condensing water, as would reduce the temperature of the water in the cylinder lower than 100°, and which would consequently cool the cylinder itself to that temperature. Under these circumstances, the descent of the piston was found to suffer very little resistance from any vapour within the cylinder; but then on the subsequent ascent, an immense waste of steam ensued. For, on being admitted under the piston, the cold cylinder and water of condensation immediately condensed the steam, and continued to do so, until the cylinder became heated again up to 212°, to which point the whole cylinder should be again heated before the ascent could be completed. Here, then, was an obvious and an extensive source of the waste of heat. At every descent of the piston, the cylinder should be cooled to below 100°; and at every ascent it should be again heated to 212°. It, therefore, became a question whether the force gained by the increased perfection of the vacuum, was adequate to

the waste of fuel in producing the vacuum; and it was found, on the whole, more profitable not to cool the cylinder to so low a temperature, and consequently to work with a very imperfect vacuum, and a diminished power.

Watt, therefore, found the atmospheric engine in this dilemma: either much or little condensation-water was to be used. If much were used, the vacuum would be perfect; but then the cylinder would be cooled, and would entail an extensive waste of fuel in heating it. If little were used, a vapour would remain, which would resist the descent of the piston, and rob the atmosphere of a part of its power. The great problem then pressed itself on his attention, *to condense the steam without cooling the cylinder.*

From the small quantity of water in the form of steam which filled the cylinder, and the large quantity of injected water to which this communicated heat, Watt was led to enquire what proportion the bulk of water in the liquid state bore to its bulk in the vaporous state; and also what proportion subsisted between the heat which it contained in these two states. He found by experiment that a cubic inch of water formed a cubic foot of steam; and that the cubic foot of steam contained as much heat as would raise a cubic inch of water to about 800°. (19) This gave him some surprise, as the thermometer indicated the same temperature, 212°, for both the steam and the water from which it was raised. What then became of all the additional heat which was contained in the steam, and not indicated by the thermometer? Watt concluded that this heat must

be in some way engaged in maintaining the liquid in its new form.

Struck with the singularity of this circumstance, he communicated it to Dr. Black, who then explained to Watt his doctrine of *latent heat*, which he had been teaching for a short time before that, but of which Watt had not previously heard; and thus, says Watt, "I stumbled upon one of the material facts on which that theory is founded."

(44.) Watt now gave his whole mind to the consideration of a method of "condensing the steam without cooling the cylinder." The idea occurred to him of providing a vessel separate from the cylinder, in which a constant vacuum might be kept up. If a communication could be opened between the cylinder and this vessel, the steam, by its expansive property, would rush from the cylinder to this vessel, where, being exposed to cold, it would be immediately condensed, the cylinder meanwhile being sustained at the temperature of 212°.

This happy conception formed the first step of that brilliant career, which has immortalized the name of Watt, and which has spread his fame to the very skirts of civilization. He states, that the moment the notion of "separate condensation" struck him, all the other details of his improved engine followed in rapid and immediate succession, so that in the course of a day his invention was so complete, that he proceeded to submit it to experiment.

His first notion was, as we have stated, to provide a separate vessel, called a *condenser*, having a pipe or

tube communicating with the cylinder. This condenser he proposed to keep cold by being immersed in a cistern of cold water, and by providing a jet of cold water to play within it. When the communication with the cylinder is opened, the steam, rushing into the condenser, is immediately condensed by the jet and the cold surface. But here a difficulty presented itself, viz. how to dispose of the condensing water, and condensed steam, which would collect in the bottom of the condenser? Besides this a certain quantity of air would inevitably enter combined with the condensing water, which, accumulating, would collect in the cylinder and resist the descent of the piston. To remedy this he proposed *to form a communication between the bottom of the condenser and a pump which he called the* AIR PUMP, *so that the water and air, or other fluids, which might be collected in the condenser, would thus be drawn off;* and it was easy to see how this pump could be worked by the machine itself. This constituted the second great step in the invention.

It had been found necessary, that the piston might move air-tight in the cylinder, to keep a quantity of water supplied above it. In the present case, any of this water which might escape through the piston, or between it and the cylinder, would boil, the cylinder being proposed to be kept at 212°; and would thus, by the steam it would produce, vitiate the vacuum. To avoid this inconvenience, Watt proposed to lubricate the piston, and keep it air-tight, by employing melted wax and tallow.

Another inconvenience was still to be removed. On

the descent of the piston, the air which entered the cylinder would lower its temperature; so that, upon the next ascent, some of the steam which entered it would be condensed, and hence would arise a source of waste. To remove this difficulty, Watt proposed to close the top of the cylinder altogether, by an air-tight and steam-tight cover, allowing the piston-rod to play through a hole furnished with a stuffing-box, and *to press down the piston by steam instead of the atmosphere.*

This was the third step in this great invention, and one which totally changed the character of the machine. It now became really a *steam-engine* in every sense; for the pressure above the piston was the elastic force of steam, and the vacuum below it was produced by the condensation of steam; so that steam was used both directly and indirectly as a moving power; whereas, in the atmospheric engine, the indirect force of steam only was used, being adopted merely as an easy method of producing a vacuum.

The last difficulty respecting the economy of heat which remained to be removed, was the circumstance of the cylinder being liable to be cooled on the external surface by the atmosphere. To obviate this, he first proposed casing the cylinder in wood, as being a substance which conducted heat slowly. He subsequently, however, adopted a different method, and enclosed one cylinder within another, leaving a space between them, which he kept constantly supplied with steam. Thus the inner cylinder was kept constantly up to the temperature of the steam which

which surrounded it. The outer cylinder is called the *jacket*.*

(45.) Watt computed that in the atmospheric engine three times as much heat was wasted in heating the cylinder, &c. as was spent in useful effect. And, as by the improvements proposed by him nearly all waste was removed, he contemplated, and afterwards actually effected, a saving of three-fourths of the fuel.

The honour due to Watt for his discoveries is enhanced by the difficulties under which he laboured from contracted circumstances at the time he made them. He relates, that when he was endeavouring to determine the heat consumed in the production of steam, his means did not permit him to use an efficient and proper apparatus, which would have been attended with expense; and it was by experiments made with apothecaries' phials, that he discovered the property already mentioned, and which was one of the facts on which the doctrine of latent heat was founded.

A large share of the merit of Watt's discoveries has, by some writers, been attributed to Dr. Black, to whose instructions on the subject of latent heat, &c. it is said that Watt owed the knowledge of those facts which led to his improvements. Such, however, was not the case; and the mistake arose chiefly from

* It is a remarkable circumstance, that Watt used the same means for keeping the cylinder hot, as Newcomen used in his earlier engines to cool it. (34)

some passages respecting Watt in the works of Dr. Robison, in one of which he states himself to have been a *pupil* and intimate friend of Dr. Black; and that he attended two courses of his lectures at college in Glasgow. Such, however, was not the case; for, "Unfortunately for me," says Watt in a letter to Dr. Brewster, "the necessary avocations of my business prevented me from attending his or any other lectures at college. In further noticing Dr. Black's opinion, that his fortunate observation of what happens in the formation and condensation of elastic vapour 'has contributed in no inconsiderable degree to the public good, by suggesting to my friend Mr. Watt of Birmingham, then of Glasgow, his improvements on the steam-engine,' it is very painful for me to controvert any opinion or assertion of my revered friend; yet, in the present case I find it necessary to say, that he appears to me to have fallen into an error. These improvements proceeded upon the established fact, that steam was condensed by the contact of cold bodies, and the later known one, that water boiled at heats below 100°, and consequently that a vacuum could not be obtained unless the cylinder and its contents were cooled every stroke below that heat."

LECTURE V.

WATT's single-acting Steam-Engine — Expansive principle applied — Failure of Roebuck, and partnership with Bolton — Patent extended to 1800 — Counter — Difficulties in getting the Engines into use.

(46.) THE first machine in which Watt realized the conceptions which we mentioned in the last lecture, is that which was afterwards called his *Single-acting Steam-Engine.* We shall now describe the working apparatus in this machine.

The cylinder is represented at C—(fig. 12) in which the piston P moves steam-tight. It is closed at the top, and the piston rod being very accurately turned, runs in a steam-tight collar B furnished with a stuffing-box, and constantly supplied with melted tallow or wax. Through a funnel in the top of the cylinder, melted grease is let in on the piston so as to maintain it steam-tight. Two boxes A A, containing the valves for admitting and withdrawing the steam, connected by a tube of communication T, are attached to the

cylinder; the action of these valves will be presently described. Below the cylinder, placed in a cistern of cold water, is a close cylindrical vessel D, called the condenser, communicating with the cylinder by a tube T′, leading to the lower valve box A. In the side of this condenser is inserted a tube, the inner end of which is pierced with holes like the rose of a watering-pot, and a cock E in the cold cistern is placed on the outside, through which, when open, the water passing, rises in a jet on the inside.

The tube S which conducts steam from the boiler, enters the top of the upper valve box at F. Immediately under it is placed a valve G which is opened and closed by a lever or rod G′. This valve, when open, admits steam to the top of the piston, and also to the tube T, which communicates between the two valve boxes, and when closed, suspends the admission of steam. There are two valves in the lower box, one H in the top worked by the lever H′, and one I in the bottom worked by the lever I. The valve H when open, admits steam to pass from the cylinder *above* the piston, by the tube T, to the cylinder *below* the piston, the valve I being supposed in this case to be closed. This valve I when open (the valve H being closed) admits steam to pass from below the cylinder through T′ to the condenser. This steam entering the condenser, meets the jet, admitted to play by the valve E, and is condensed.

The valve G is called the *upper steam-valve;* H, the *lower steam-valve;* I, the *exhausting valve;* and E, the *condensing valve.* Let us now consider how these

valves must be worked in order to produce the alternate ascent and descent of the piston.

It is in the first place necessary, that all the air which fills the cylinder, tubes, and condenser, should be expelled. To accomplish this, it is only necessary to open at once the valves G, H, and I. The steam then rushing from F through the valve G will pass into the upper part of the cylinder, and through the tube T and the valve H into the lower part, and also through the valve I into the condenser. After the steam ceases to be condensed by the cold of the apparatus, it will rush out mixed with air through the valve M which opens outwards; and this will continue until all the air has been expelled, and the apparatus filled with pure steam. Then suppose all the valves again closed. The cylinder both above and below the piston is filled with steam; and the steam which filled the condenser being cooled by the cold surface, a vacuum has been produced in that vessel.

The apparatus being in this state, let the upper steam valve G, the exhausting valve I, and the condensing valve E be opened. Steam will thus be admitted through G to press on the top of the piston; and this steam will be prevented from circulating to the lower part of the cylinder by the lower steam-valve H being closed. Also the steam which filled the cylinder below the piston rushes through the open exhausting valve I to the condenser where it meets the jet allowed to play by the open condensing valve E. It is thus instantly condensed, and a

vacuum is left in the cylinder below the piston. Into this vacuum the piston is pressed without resistance by the steam which is admitted through G. When the piston has thus been forced to the bottom of the cylinder, let the three valves G, I, and E, which were before opened, be closed, and let the lower steam-valve H be opened.. The effects of this change are easily perceived. By closing the upper steam-valve G, the further admission of steam to the apparatus is stopped. By closing the exhausting valve I, all transmission of steam from the cylinder to the condenser is stopped. Thus the steam which is *in* the cylinder, valve-boxes, and tubes is shut up in them, and no more admitted, nor any allowed to escape. By closing the condensing valve E, the play of the jet in the condenser is suspended.

Previously to opening the valve H, the steam contained in the apparatus was confined to the part of the cylinder *above* the piston and the tube T and valve box A. But on opening this valve, the steam is allowed to circulate above and below the piston; and in fact through every part included between the upper steam valve G, and the exhausting valve I. The same steam circulating on both sides, the piston is thus equally pressed upwards and downwards.

In this case there is no force tending to retain the piston at the bottom of the cylinder except its own weight. Its ascent is produced in the same manner as the ascent of the piston in the atmospheric engine. The piston-rod is connected by chains G, to the arch-head of the beam, and the weight of the pump-rod B

or any other counterpoise acting on the chains suspended from the other arch-head draws the piston to the top of the cylinder.

When the piston has arrived at the top of the cylinder, suppose the three valves G, I, and E to be again opened, and H closed. Steam passes from the steam-pipe F through the upper steam valve G to the top of the piston and at the same time the steam which filled the cylinder, below the piston is drawn off through the open exhausting valve I into the condenser where it is condensed by the jet allowed to play by the open condensing valve E. The pressure of the steam above the piston then forces it without resistance into the vacuum below it, and so the process is continued.

It should be remembered, that of the four valves necessary to work the piston, three are to be opened the moment the piston reaches the top of the cylinder, and the fourth is to be closed; and on the piston arriving at the bottom of the cylinder, these three are to be closed and the fourth opened. The three valves which are thus opened and closed together, are the upper steam-valve, the exhausting-valve, and the condensing-valve. The lower steam-valve is to be opened at the same instant that these are closed, and *vice versâ*. The manner of working these valves we shall describe hereafter.

(47.) The process which has just been described, if continued for any considerable number of reciprocations of the piston, would be attended with two very obvious effects which would obstruct and finally de-

stroy the action of the machine. First the condensing water and condensed steam would collect in the condenser D, and fill it, and secondly the water in the cistern in which the condenser is placed, would gradually become heated, until at last it would not be cold enough to condense the steam when introduced in the jet. Besides this it will be recollected that water boils in a vacuum at a very low temperature (17); and, therefore, the hot water collected in the bottom of the condenser would produce steam which, rising into the cylinder through the exhausting-valve, would resist the descent of the piston, and counteract the effects of the steam above it. A further disadvantage arises from the air or other permanently elastic fluid which enters in the jet in combination with the water, and which is disengaged by its own elasticity in the vacuum produced in the condenser.

To remove these difficulties, a pump is placed near the condenser communicating with it by a valve M, which opens from the condenser into the pump. In this pump is placed a piston which moves air-tight, and in which there is a valve N which opens upwards. Now suppose the piston at the bottom of the pump. As it rises, since the valve in it opens *upwards*, no air can pass *down* through it, and consequently it leaves a vacuum *below* it. The water and any air which may be collected in the condenser open the valve M, and pass into the lower part of the pump, from which they cannot return in consequence of the valve M opening *outwards*. On the descent of the pump-piston, the fluids which occupy the lower part of the pump, force open the piston-valve N, and passing

through it get *above* the piston from which their return is prevented by the valve N. In the next ascent, the piston lifts these fluids to the top of the pump, whence they are discharged through a conduit into a small cistern B by a valve K which opens outwards. The water which is thus collected in B is heated by the condensed steam, and is reserved in B which is called the hot-well for feeding the boiler, which is effected by means which we shall presently explain. The pump which draws off the hot water and air from the condenser is called the *air-pump*.

(48.) We have not yet explained the manner in which the valves and the air-pump piston are worked. The rod Q of the latter is connected with the working beam, and the pump is therefore wrought by the engine itself. It is not very material to which arm of the beam it is attached. If it be on the same side of the centre of the beam with the cylinder, it rises and falls with the steam-piston; but if it be on the opposite side, the pump-piston rises when the steam-piston falls, and *vice versâ*. In the single-engine there are some advantages in the latter arrangement. As the steam-piston *descends*, the steam rushes into the condenser, and the jet is playing, and this, therefore, is the most favorable time for drawing out the water and condensed steam from the condenser by the ascent of the pump-piston, since by this means the descent of the steam-piston is assisted, an effect which would not be produced if the steam-piston and pump-piston descended together.

With respect to the method of opening and closing

the valves, it is evident that the three valves which are simultaneously opened and closed, may be so connected as to be worked by the same lever. This lever may be struck by a pin fixed upon the rod Q of the air-pump, so that when the pistons have arrived at the top of the cylinders, the pin strikes the lever and opens the three valves. A catch or detent is provided for keeping them open during the descent of the piston, from which they are disengaged in a similar manner on the arrival of the piston at the bottom of the cylinder, and they close by their own weight.

In exactly the same way the lower steam-valve is opened on the arrival of the piston at the bottom of the cylinder, and closed on its arrival at the top by the action of a pin placed on the piston-rod of the air-pump.

(49.) Soon after the invention of these engines, Watt found that in some instances inconvenience arose from the too rapid motion of the steam-piston at the end of its stroke, owing to its being moved with an *accelerated motion*. This was owing to the uniform action of the steam-pressure upon it. For upon first putting it in motion at the top of the cylinder, the motion was comparatively slow, but from the continuance of the same pressure the velocity with which the piston descended was continually increasing, until it reached the bottom of the cylinder where it acquired its greatest velocity. To prevent this, and to render the descent as nearly as possible uniform, it was proposed to cut off the steam before the descent was completed, so that the remainder might be effect-

ed merely by the expansion of the steam which was admitted to the cylinder. To accomplish this, he contrived, by means of a pin on the rod of the air-pump, to close the upper steam-valve when the steam-piston had completed one-third of its entire descent, and to keep it closed during the remainder of the descent, and until the piston again reached the top of the cylinder. By this arrangement the steam pressed the piston with its full force through one-third of the descent, and thus put it into motion; during the other two-thirds the steam thus admitted acted merely by its expansive force, which became less in exactly the same proportion as the space given to it by the descent of the piston increased. Thus during the last two-thirds of the descent the piston is urged by a gradually decreasing force which in practice was found just sufficient to keep up in the piston an uniform velocity.

Another advantage gained by this contrivance independently of the uniformity of the motion was, that two-thirds of the fuel were saved; for instead of consuming a cylinder full of steam, each descent of the piston, only one-third of a cylinder full was necessary.

(50.) We have already mentioned the difficulty arising from the water in the cistern, in which the condenser and air-pump are placed, becoming heated, and the condensation therefore becoming imperfect. To prevent this, a waste-pipe is placed in this cistern, from which the water is continually discharged, and a pump L (called the *cold water pump*) is worked by the

engine itself, which raises a supply of cold water and sends it through a pipe in a constant stream into the cold cistern. The waste-pipe, through which the water flows from the cistern, is placed near the top of it, since the heated water being lighter than the cold, remains on the top. Thus the heated water is continually flowing off, and a constant stream of cold water supplied. The piston-rod of the cold water pump is attached to the beam (by which it is worked) usually on the opposite side from the cylinder.

Another pump o (called the *hot water pump*), enters the *hotwell* B, and raising the water from it, forces it through a tube to the boiler for the purpose of feeding it. The manner in which this is effected will be more particularly described hereafter. A part of the heat which would otherwise be lost, is thus restored to the boiler to assist in the production of fresh steam. We may consider a portion of the heat to be in this manner *circulating* continually through the machine. It proceeds from the boiler in steam; works the piston, passes into the condenser, and is reconverted into hot water; thence it is passed to the hot-well, from whence it is pumped back into the boiler, and is again converted into steam, and so proceeds in constant circulation.

(51.) From what has been described, it appears that there are four pistons attached to the great beam and worked by the piston of the steam-cylinder. On the same side of the centre with the cylinder is the piston-rod of the air-pump, and on the opposite side are the piston-rods of the hot water pump and the cold water pump, and lastly, at the extremity of the

beam opposite to that at which the steam-piston works, is the piston of the pump to be wrought by the engine.

(52.) The position of these piston-rods with respect to the centre of the beam depends on the play necessary to be given to the piston. If the play of the piston be short, its rod will be attached to the beam near the centre, and if longer, more remote from the centre. The cylinder of the air-pump is commonly half the length of the steam-cylinder, and its piston-rod is attached to the beam at the point exactly in the middle between the end of the beam and the centre. The hot water pump not being required to raise a considerable quantity of water, its piston requires but little play, and is, therefore, placed near the centre of the beam, the piston-rod of the cold water pump being farther from the centre.

(53.) It appears to have been about the year 1763, that Watt made these improvements in the steam-engine and constructed a model which fully realized his expectations. Either from want of influence or the fear of prejudice and opposition, he did not make known his discovery or attempt to secure it by a patent at that time. Having adopted the profession of a land surveyor, his business brought him into communication with Dr. Roebuck, a gentleman at that time extensively engaged in mining speculations, and who possessed some command of capital, and was of a very enterprising disposition. By Roebuck's assistance and countenance, Watt erected an engine on the new construction at a coal mine on the estate of

the Duke of Hamilton, at Kinneil near Burrowstoness. This engine being a kind of experimental one, was improved from time to time as circumstances suggested, until it reached considerable perfection. While it was being erected, Watt in conjunction with Roebuck applied for and obtained a patent to secure the property in the invention. This patent was enrolled in 1769, six years after Watt invented the improved engine.

Watt was now preparing to manufacture the new engines on an extensive scale, when his partner Roebuck suffered a considerable loss by the failure of a mining speculation in which he had engaged and became involved in embarrassments, so as to be unable to make the pecuniary advances necessary to carry Watt's designs into execution. Again disappointed, and harrassed by the difficulties which he had to encounter, Watt was about to relinquish the further prosecution of his plans, when Mr. Matthew Bolton, a gentleman who had established a factory at Birmingham a short time before, made proposals to purchase Dr. Roebuck's share in the patent, in which he succeeded; and in 1773, Watt entered into partnership with Bolton.

His situation was now completely changed. Bolton was not only a man of extensive capital, but also of considerable personal influence, and had a disposition which led him, from taste, to undertakings which were great and difficult, and which he prosecuted with the most unremitting ardency and spirit. "Mr. Watt," says Playfair, "was studious and reserved, keeping aloof from the world; while Mr. Bolton was a man of address, delighting in society,

active and mixing with people of all ranks with great freedom, and without ceremony. Had Mr. Watt searched all Europe, he probably would not have found another person so fitted to bring his invention before the public, in a manner worthy of its merit and importance; and although of most opposite habits, it fortunately so happened, that no two men ever more cordially agreed in their intercourse with each other."

The delay in the progress of the manufacture of engines occasioned by the failure of Dr. Roebuck was such, that Watt found that the duration of his patent would probably expire before he would even be reimbursed the necessary expences attending the various arrangements for the manufacture of the engines. He therefore, with the advice and influence of Bolton, Roebuck and other friends, in 1775, applied to parliament for an extension of the term of his patent, which was granted for 25 years from the date of his application, so that his exclusive privilege should expire in 1800.

An engine was now erected at Soho (the name of Bolton's factory) as a specimen for the examination of mining speculators, and the engines were beginning to come into demand. The manner in which Watt chose to receive remuneration from those who used his engines was as remarkable for its ingenuity, as for its fairness and liberality. He required that one-third of the saving of coals effected by his engines compared with the atmospheric engines hitherto used should be paid to him, leaving the benefit of the other two-thirds to the public. Accurate experiments were made to ascertain the saving of coals:

and as the amount of this saving in each engine depended on the length of time it was worked, or rather on the number of descents of the piston, Watt invented a very ingenious method of determining this. The vibrations of the great working beam were made to communicate with a train of wheelwork in the same way as those of a pendulum communicate with the work of a clock. Each vibration of the beam moved one tooth of a small wheel, and the motion was communicated to a hand or index, which moved on a kind of graduated plate like the dial plate of a clock. The position of this hand marked the number of vibrations of the beam. This apparatus which was called the *counter*, was locked up and secured by two different keys, one of which was kept by the proprietor, and the other by Bolton and Watt, whose agents went round periodically to examine the engines when the counters were opened by both parties and examined, and the number of vibrations of the beam determined, and the value of the patent third found.*

Notwithstanding the manifest superiority of these engines over the old atmospheric engines, yet such were the influence of prejudice and the dislike of what is new, that Watt found great difficulties in getting them into general use. The comparative first cost

* The extent of the saving in fuel may be judged from this: that for three engines erected at Chacewater mine in Cornwall, it was agreed by the proprietors, that they would compound for the patent third, at £2400 per annum; so that the whole saving must have exceeded £7200 per annum.

also probably operated against them, for it was necessary that all the parts should be executed with great accuracy, which entailed proportionally increased expense. In many instances they felt themselves obliged to induce the proprietors of the old atmospheric engines to replace them by the new ones, by allowing them in exchange an exorbitant price for the old engines, and in some cases they were induced to erect engines at their own expense, upon an agreement that they should only be paid if the engines were found to fulfil the expectations, and brought the advantages which they promised. It appeared since, that Bolton and Watt had actually expended a sum of nearly £50,000 on these engines before they began to receive any return. When we contemplate the immense advantages which the commercial interests of the country have gained by the improvements in the steam-engine, we cannot but look back with disgust at the influence of that fatal prejudice which opposes the progress of improvement under the pretence of resisting innovation. It would be a problem of curious calculation to determine what would have been lost to the resources of this country, if chance had not united the genius of such a man as Watt with the spirit, enterprize, and capital, of such a man as Bolton! The result would reflect little credit on those who think novelty alone a sufficient reason for opposition.

LECTURE VI.

Defects of the single engine as applied to move machinery — Attempts to remove these — by two single engines — by the double-acting engine — Its principle — parallel motion — Crank — Sun and planet wheel — Fly-wheel — Governor.

(54.) In the atmospheric engine, and the improved steam-engine of Watt, the power was of an intermitting kind. It acted only during the descent of the piston, but during the ascent its agency was suspended. Besides this, the weights or counter-poises which lifted the piston in the ascent, acted against the power in the descent; and therefore no power was really saved by the suspension of the agency of steam-pressure during the ascent; since a proportionably increased pressure was produced in the descent. Besides, being of an intermitting nature, the power acted only in one direction. If the steam-engine were only applied to pumping, these would not be defects, since an intermitting force acting always in one direction is that which is required. But if a more extended application of the powers of this machine be contemplated, these defects become serious obstacles. To drive any species of machinery, a constant and uniform action is requisite, and, therefore, the suspension of the

power during the ascent of the piston, would be incompatible with this.

Watt first proposed removing this defect by placing a cylinder under each arm of the beam, so that when one piston would be rising, the other would be falling. Thus the power would be acting on each, exactly at the time when its action on the other would be suspended, and an uniformity would be produced by making both cylinders communicate with the same boiler, so that steam of the same pressure would act upon them. They might also communicate with the same condenser, so that the same degree of condensation, and a similar vacuum would be produced in each, thus insuring an equality of action.

(55.) This arrangement, however, was soon laid aside in favour of the single cylinder, with steam pressing the piston both *upwards* and *downwards*. This was easily accomplished by opening alternate communications, by valves, between each end of the cylinder, and the boiler and condenser. Thus, when the piston is at the top of the cylinder, steam is admitted from the boiler above the piston, while the steam below it is allowed to flow into the condenser; and when the piston is at the bottom of the cylinder, steam is admitted from the boiler below it, while that which is abovei t is allowed to flow into the condenser. There is thus a vacuum formed in the cylinder, alternately, above and below the piston, into which the steam admitted on the other side presses it. Such is the principle of what is called the *double acting steam-engine*, in contradistinction to that in which, as described

in the last lecture, steam acts only on one side of the piston, while a vacuum is produced only on the other side.

In this case, the process of condensation must be constantly sustained in the condenser, for when the piston is descending, the steam *below* it is being condensed, and when it is ascending, the steam *above* it is being condensed. The jet must, therefore be kept constantly playing in the condenser, and the quantity of water which it admits, is regulated by a valve adjusted by a lever or index which moves upon a graduated arch, and which may be regulated by the engineer when the engine is set at work.

(56.) This change in the action of the first mover occasioned a necessity for a change in the manner of connecting the piston-rod with the beam. In the single-acting engine, the end of the beam *pulled* the piston-rod *up*, and the piston-rod *pulled* the end of the beam *down*. In both these cases, therefore, a flexible chain, applying itself to the arch-head of the beam, evidently transmitted the force. But in the double-acting engine it is quite otherwise. In the descent, it is true, that the piston-rod still *pulls* the beam *down*, but in the ascent the beam no longer *pulls up* the piston-rod, but is *pushed up* by it. Now, a flexible chain, though an effective agent in transmitting that modification of force called a *pull*, is incapable of communicating a *push* or *thrust*. Were the chain and arch-head to be used in a double engine, (which has no counter weight on the opposite end of the beam to pull it up) the consequence would be

that, in the ascent of the piston, the chain would slacken, and the end of the beam above the piston-rod still remain depressed.

It is, therefore, necessary that the connexion of the piston-rod with the end of the beam should not be flexible but rigid, so as to be capable of transmitting force, both by *pulling* and *pushing*. Watt first proposed effecting this by making the piston-rod terminate in a rack with teeth, which should play in corresponding teeth raised on the arch head of the beam as in fig. 13.

(57.) Against this method, however, there were some objections, as it was liable to wear, and failed to give that smoothness of motion to the piston-rod which is essentially necessary for the preservation of the condition of the engine. The problem, therefore, which presented itself for solution, was to convert a perfectly smooth and straight motion of the piston-rod into a circular motion in the end of the beam,* and the genius of Watt never was more clearly manifested than in his solution of this problem.

He conceived the notion of two straight rods A B, C D (fig. 14.) moving on centres or pivots A and C, so that the ends B and D would move in arcs of circles, with A and C as centres. The extremities B and D of these rods he conceived to be connected by a third rod B D, united with them by pivots at B and D, on which it could turn freely. To the system of

* Technically "to convert a reciprocating rectilinear motion into a reciprocating circular motion."

rods thus connected, let an alternate motion round the fixed centres A and C be communicated. The points B and D will move in arcs with centres at A and C respectively, but the middle point P of the connecting-rod BD will move upwards and downwards in a straight line. *

His manner of reducing this mathematical principle to practical application was as elegant as the notion itself was ingenious.

The apparatus is represented on the arm of the beam which works the piston in fig. 15. The beam, moving on its axis C, every point in its arm moves in the arc of a circle of which C is the centre. Let B be the point which divides the arm A C into equal parts, A B and B C; and let D E be a straight rod equal in length to C B, and playing on the fixed centre or pivot D. The end E of this rod is connected by a straight bar E B with the point B, by pivots at B and E, on which the rod B E turns freely. If the beam be supposed to move alternately on its axis C, the point B will move up and down in a circular arc, of which C is the centre; and at the same time the point E will move in an equal circular arc round the point D as a centre. According to what we have just

* In a strict mathematical sense, the path of the point P is a curve of an high order, but in the play which is given to it in the application used in the steam-engine, it describes only a part of its entire locus, and this part extending equally on each side of a point of inflection, its radius of curvature is infinite, so that in practice, the deviation from a straight line, when proper proportions are observed in the rods, is imperceptible.

[illegible] the middle point F of the rod D E will move up and down in a straight line.

Also, let a rod A G, equal in length to D E, be attached to the end A of the beam by a pivot on which it moves freely; and let its extremity G be connected with E by a rod G E, equal in length to A D, and playing on pivots at G and E. The point G will move in a straight line parallel to that in which F moves.* The piston-rod of the steam-piston is attached to the point G, and that of the air-pump is attached to the point F, so that they are thus moved in parallel straight lines, one having double the motion of the other, being double the distance from the centre C.†

This beautiful contrivance is called the *parallel motion*, and is an instance of the result of a complicated mathematical analysis perceived instinctively, and apparently without any chain of connected reasoning. Watt was asked by those whose admiration was justly excited by this exquisite invention, to what reasoning he could trace back his discovery; and he replied that

* The points C, F and G evidently lie in the same straight line, since CB : CA :: BF : AG, and the latter lines are parallel. Taking C as the common *pole* of the *loci* of the points F, G, the *radius vector* of the one will always be twice the corresponding *radius vector* of the other; and, therefore, these curves are similar, similarly placed and parallel. Hence, by the last note, the point G must move in a line, differing imperceptibly from a right line.

† It is not necessary that the rods, forming the parallel motion, should have the proportions which we have assigned to them. There are various proportions which answer the purpose, and which will be seen by reference to works on the steam-engine.

he was aware of none; that the conception flashed upon his mind without previous investigation, and so as to excite in himself surprise at the perfection of its action; and that in looking at it for the first time, he experienced all that pleasurable sense of novelty which arises from the first contemplation of the results of the invention of others.

This and the other inventions of Watt seem to have been the pure creations of his genius, very little assisted by the results of practice. It does not even appear that he was a dexterous mechanic; for he never assisted in the construction of the first models of his own inventions. His dwelling-house was two miles from the factory, to which he never went more than once in the week, and then did not stay half an hour.

(58.) A perfect method being thus obtained of conveying the alternate motion of the piston to the working beam, the use of a counterpoise to lift the piston was discontinued, and the beam was made to balance itself exactly on its centre. The next end to be obtained was to adapt the vibrating force of the working end of the beam to the motion of machinery. The motion most generally useful for this purpose is one of *continued rotation*. The object, therefore, was by the *alternate circular* motion of the end of the beam to produce a *continued circular* motion. In the first instance, Watt proposed effecting this by a *crank*, connected with the working end of the beam by a metal connector or rod.

Let K be the centre or axis of the wheel which works

the machinery, and to which rotation is to be imparted by the beam A. On the axis x, suppose a lever x 1 fixed, so that when x is turned round the centre x, the wheel must be turned with it. Let a connecter or rod be attached to the points 1 and 2, playing freely on pivots or joints. As the end 2 is moved upwards and downwards, the lever x 1 is turned round the centre x, so as to give a continued rotary motion to the wheel which revolves on that centre. The different positions which the connecter and lever x 1 assume in the different parts of a revolution are represented in fig. 16.

(59.) This was the first method which occurred to Watt for producing a continued rotatory motion by means of the vibrating motion of the beam, and is the method now universally used. A workman, however, from Mr. Watt's factory, who was aware of the construction of a model of this, communicated the method to Mr. Washborough of Bristol, who anticipated Watt in taking out a patent, and although it was in his power to have disputed the patent, yet rather than be involved in litigation, he gave up the point, and contrived another way of producing the same effect, which he called the *sun and planet* wheel, and which he used until expiration of the Washborough's patent, when the crank was resumed.

The toothed wheel B (fig. 17.) is fixed on the end of the connector, so that it does not turn on its axis. The teeth of this wheel work in those of another wheel A, which is the wheel to which rotation is to be imparted, and which is turned by the wheel B revolv-

ing round it, urged by the rod H I, which receives its motion from the working-beam. The wheel A is called the sun-wheel, and B the planet wheel, from the obvious resemblance to the motion of these bodies.

This contrivance, although in the main inferior to the more simple one of the crank, is not without some peculiar advantages; among others, it gives to the sun-wheel double the velocity which would be communicated by the simple crank, for in the simple crank one revolution only of the axle is produced by one revolution of the crank, but in the sun-and-planet wheel two revolutions of the sun-wheel are produced by one of the planet-wheel; thus a double velocity is obtained from the same motion of the beam. This will be evident from considering that when the planet wheel is in its highest position, its lowest tooth is engaged with the highest tooth of the sun-wheel, as the planet-wheel passes from the highest position, its teeth driving those of the sun-wheel before them; when it comes into the lowest position, the highest tooth of the planet wheel is engaged with the lowest of the sun wheel: but then half of the sun-wheel has *rolled off* the planet-wheel, and therefore, the tooth which was engaged with it in its highest position, must now be distant from it by half the circumference of the wheel. A little reflection, however, on the nature of the motion, will render this plainer than any description can. This advantage of giving an increased velocity, may be obtained also by the simple crank, by placing toothed wheels on its axle. Independently of the greater expense attending the construction of the sun-and-planet-wheel, its liability to

go out of order, and the rapid wear of the teeth and other objections, rendered it decidedly inferior to the crank, which has now entirely superseded it.

(60.) Whether the simple crank or the sun-and-planet wheel be used, there is a difficulty of a peculiar nature attending the continuance of the rotatory motion which is still to be overcome. There are two positions in which the engine can give no motion whatever to the crank, and these are when the end of the beam, the axle of the crank, and the pivot which joins the connector with the crank, are in the same straight line. This will be easily understood. Suppose the beam, connector, and crank to assume the position represented in fig. 15. If steam urge the piston downwards, the point H and the connector H I will be drawn directly upwards. But it must be very evident that in the present situation of the connector H I, and the lever I K, the force which draws the point I in the direction I K can have no effect whatever in turning I K round the centre K, but will merely exert a pressure on the axle or pivots of the wheel.

Again, suppose the crank and connector to be in the position H I K (fig. 16.), the piston being consequently at the bottom of the cylinder. If steam now press the piston *upwards*, the pivot H and the connector H I will be pressed *downwards*, and this pressure will urge the crank I K in the direction I K. It is evident that such a force cannot turn the crank round the centre K, and can be attended with no other effect than a pressure on the axle or pivots of the wheel.

Hence in these two positions, the engine can have no effect whatever in turning the crank. What then, it may be asked, extricates the machine from the mechanical dilemma in which it is placed twice in every revolution, on arriving at those positions in which the crank escapes the influence of the powe ? There is a tendency in bodies, when once put in motion, to continue that motion until stopped by some opposing force, and this tendency carries the crank out of those two critical situations. The velocity which is given to it, while it is under the influence of the impelling force of the beam, is retained in a sufficient degree to carry it through that situation in which it is deserted by this impelling force. Although the rotatory motion intended to be produced by the crank is, therefore, not absolutely impeded by this circumstance, yet it is rendered extremely irregular since, in passing through the two positions already described, where the machine loses its power over the crank, the motion will be very slow, and, in the positions of the crank most remote from these where the power of the beam upon it is greatest, the motion will be very quick. As the crank revolves from each of those positions where the power of the machine over it is greatest, to where that power is altogether lost, it is continually diminished, so that in fact the crank is driven by a varying power, and so produces a varying motion. This will be easily understood by considering the successive positions of the crank and connector represented in fig. 16.

This variable motion becomes particularly objectionable when the engine is employed to drive ma-

chinery. To remove this defect, we have recourse to the property of bodies just mentioned, viz. their tendency to retain a motion which is communicated to them. A large metal wheel called a *fly-wheel* is placed upon the axis of the crank (fig. 15.), and is turned by it. The effect of this wheel is to equalize the motion communicated by the action of the beam on the crank, that action being just sufficient to sustain in the fly-wheel an uniform velocity, and the tendency of this wheel to retain the velocity it receives, renders its rotation sufficiently uniform for all practical purposes.

This uniformity of motion, however, will only be preserved on two conditions, *first*, that the supply of steam from the boiler shall be uniform, and secondly that the machine have always the same resistance to overcome or be *loaded* equally. If the supply of steam from the boiler to the cylinder be increased, the motion of the piston will be rendered more rapid, and, therefore, the revolution of the fly-wheel will also be more rapid, and on the other hand a diminished supply of steam will retard the fly-wheel. Again, if the resistance or load upon the engine be diminished, the supply of steam remaining the same, the velocity will be increased, since a less resistance is opposed to the energy of the moving power, and on the other hand if the resistance or load be increased, the speed will be diminished, since a greater resistance will be opposed to the same moving power. To insure an uniform velocity, in whatever manner the load or resistance may be changed, it is necessary to proportion the supply of steam to the resistance, so that

upon the least variation in the velocity, the supply of steam will be increased or diminished, so as to keep the engine going at the same rate.

(61.) One of the most striking and elegant appendages of the steam-engine is the apparatus contrived by Watt for effecting this purpose. An apparatus, called a *regulator* or *governor*, had been long well known to mill-wrights for rendering uniform the action of the stones in corn mills, and was used generally in machinery. Mr. Watt contrived a beautiful application of this apparatus for the regulation of the steam-engine. In the pipe which conducts steam from the boiler to the cylinder he placed a thin circular plate, so that when placed with its face presented towards the length of the pipe, it nearly stopped it, and allowed little or no steam to pass to the cylinder, but when its edge was placed in the direction of the pipe, it offered no resistance whatever to the passage of the steam. This circular plate was made to turn on a diameter as an axis, passing consequently through the centre of the tube. This plate or valve, called the throttle valve, was turned by a lever outside the tube, and according to the position given to it, would permit more or less steam to pass. If the valve be placed with its edge nearly in the direction of the tube, the supply of steam is abundant; if it be placed with its face nearly in the direction of the tube, the supply of steam is more limited, and it appears that by the position given to this valve, the steam may be measured in any quantity to the cylinder.

At first it was proposed that the engine-man should adjust this valve with his hand; when the engine was observed to increase its speed too much, he would check the supply of steam by partially closing the valve, but if on the other hand the motion was too slow, he would open the valve and let in a more abundant supply of steam. Watt, however, was not content with this, and desired to make the engine itself discharge this task with more steadiness and regularity than any attendant could, and for this purpose he applied the governor already alluded to.

This apparatus is represented in fig. 15; L is a perpendicular shaft or axle to which a wheel M with a groove is attached, and which turns with the shaft in pivots at the ends of the shaft L. A strap or rope which is rolled upon the axle of the fly-wheel is passed round the groove in the wheel M, in the same manner as the strap acts in a turning lathe. By means of this strap the rotation of the fly-wheel will produce a rotation of the wheel M and the shaft L, and the speed of the one will always increase or diminish in the same proportion as the speed of the other. N, N are two heavy balls of metal placed at the ends of rods, which play on an axis fixed on the revolving shaft at O, and extend beyond the axis to Q, Q. Connected with these by joints at Q Q are two other rods Q R, which are attached to a broad ring of metal, moving freely up and down the revolving shaft. This ring is attached to a lever whose centre is S, and is connected by a series of levers with the throttle-valve T. When the speed of the fly-wheel is much increased, the spindle L is whirled

round with considerable rapidity, and by their natural tendency* the balls N N fly from the centre. The levers which play on the axis O, by this motion, diverge from each other, and, thereby depress the joints Q Q, and by this draw down the joints R, and with them the ring of metal which slides upon spindle. By these means the end of the lever playing on S is depressed, and the end V raised, and the motion is transmitted to the throttle-valve which is thereby partially closed, and the supply of steam to the cylinder checked. If, on the contrary, the velocity of the fly-wheel be diminished, the balls will fall towards the axis, and the opposite effects ensuing, the supply of steam will be increased, and the velocity restored.

The peculiar beauty of this apparatus is, that in whatever position the balls settle themselves, the velocity with which the governor revolves must be the same;† and in this, in fact, consists its whole efficacy as a regulator. Let us suppose that the en-

* The *centrifugal force.*

† Strictly speaking, this is only true when the divergence of the rods from the spindle is not very great, and in practice, this divergence is never sufficient to render the above assertion untrue. This property of the conical pendulum arises from the circumstance of the centrifugal force, in this instance, varying as the radius of the circle in which the balls are moved; and when this is the case, as is well known, the *periodic time* is constant. The time of one revolution of the balls is equal to twice the time in which either ball, as a common pendulum, would vibrate on the centre, and as all its vibrations, though the arcs be unequal, are equal in time,

gine is working 100 looms, and that 50 of them are thrown out of gear. The engine is thus suddenly relieved of half its load, and the supply of steam before employed, will now make it move with a considerably increased velocity. The balls will immediately fly from the axis and partially close the throttle-valve, and diminish the supply of steam. When this is so far accomplished as to restore the engine to its former velocity, the balls will become steady, and continue to revolve at the increased distance from the axis with the same velocity as they before revolved at the original distance.

We have thus described the principal parts of the double acting steam-engine. The valves and the methods of working them have been reserved for the next lecture, as they admit of considerable variety, and will be better treated of separately. We have also reserved the consideration of the boiler, which is far from being the least interesting part of the modern steam-engine, for a future lecture.

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provided those arcs be small, so also is the periodic time of the revolving balls invariable. These observations, however, only apply when the balls settle themselves steadily into a circular motion; for while they are ascending they describe a a spiral curve with double curvature, and the period will vary. This takes place during the momentary changes in the velocity of the engine.

effected by four valves, which were opened and closed in pairs. Valve boxes were placed at the top and bottom of the cylinder, each of which communicated by tubes with both the steam-pipe from the boiler and the condenser. Each valve-box accordingly contained two valves, one to admit steam from the steam-pipe to the cylinder, and the other to allow that steam to pass into the condenser. Thus each valve-box contained a steam valve and an exhausting valve. The valves at the top of the cylinder are called the *upper steam valve*, and the *upper exhausting valve*, and those at the bottom the *lower steam valve* and the *lower exhausting valve*. In fig. 15. A′ is the upper steam valve, which when open admits steam above the piston; B′ is the upper exhausting valve, which when open draws off the steam from the piston to the condenser. C′ is the lower steam valve, which admits steam below the piston, and D′ the lower exhausting valve, which draws off the steam from below the piston to the condenser.

Now, suppose the piston to be at the top of the cylinder, the cylinder below it being filled with steam, which has just pressed it up. Let the *upper steam valve* A′, and the *lower exhausting valve* D′ be opened, and the other two valves closed. The steam which fills the cylinder below the piston will immediately pass through the valve D′ into the condenser, and a vacuum will be produced below the piston. At the same time, steam is admitted from the steam-pipe through the valve A′ above the piston, and its pressure will force the piston to the bottom of the cylinder. On the arrival of the piston at the bottom of the cylinder,

the upper steam valve A′, and lower exhausting valve D′, are closed, and the lower steam valve c′, and upper exhausting valve B′ are opened. The steam which fills the cylinder above the piston now passes off through B′ into the condenser, and leaves a vacuum above the piston. At the same time, steam from the boiler is admitted through the lower steam valve c′, below the piston, so that it will press the piston to the top of the cylinder; and so the process is continued.

It appears, therefore, that the upper steam valve, and the lower exhausting valve, are to be opened together, on the arrival of the piston at the top of the cylinder. To effect this, one lever E′ is made to communicate by jointed rods with both these valves, and this lever is moved by a pin placed on the piston-rod of the air-pump; and such a position may be given to this pin as to produce the desired effect exactly at the proper moment of time. In like manner, another lever F′ communicates by jointed rods with the upper exhausting valve and lower steam valve, so as to open them and close them together; and this lever in like manner is worked by a pin in the piston-rod of the air-pump.

(63.) This method of connecting the valves, and working them, has been superseded by another, for which Mr. MURRAY of Leeds obtained a patent, which was, however, set aside by Messrs. Bolton and Watt, who shewed that they had previously practised it. This method is represented in fig. 18, 19. The stems of the valves are perpendicular, and move in

steam-tight sockets in the top of the valve-boxes. The stem of the upper steam valve A is a tube through which the stem of the upper exhausting valve B passes, and in which it moves steam-tight; both these stems moving steam-tight through the top of the valve-box. The lower steam valve C, and exhausting valve D, are similarly circumstanced; the stem of the former being a tube through which the stem of the latter passes. The stems of the upper steam valve and lower exhausting valve are then connected by a rod E; and those of the upper exhausting valve and lower steam valve by another rod F. These rods, therefore, are capable of moving the valves in pairs, when elevated and depressed. The motion which works the valves is, however, not communicated by the rod of the air-pump, but is received from the axis of the fly wheel. This axis works an apparatus called an *eccentric;* the principle which regulates the motion of this may be thus explained:

D E (fig. 20, 21.) is a circular metallic ring, the inner surface of which is perfectly smooth. This ring is connected with a shaft F B, which communicates motion to the valves by levers which are attached to it at B. A circular metallic plate is fitted in the ring so as to be capable of turning within it, the surfaces of the ring and plate which are in contact being smooth and lubricated with oil or grease. This circular plate revolves, but not on its centre. It turns on its axis C, at some distance from its centre A; the effect of which, evidently, is that the ring within which it is turned is moved alternately in opposite directions, and through a space equal to twice the

distance (C A) of the axis of the circular plate from the common centre of it and the ring. The eccentric in its two extreme positions is represented in fig. 20, 21. The plate and ring D E are placed on the axis of the fly-wheel, or on the axis of some other wheel which is worked by the fly-wheel. So that the motion of continued rotation in the fly-wheel is thus made to produce an alternate motion in a straight line in the shaft F B. This rod is made to communicate by levers with the rods E and F (fig. 18, 19), which work the valves in such a manner, that when the eccentric is in the position fig. 20. one pair of valves are opened and the other pair closed; and when it is brought to the position fig. 21. the other pair are opened, and the former closed, and so on. It is by means of such an apparatus as this, that the valves are worked almost universally at present.

The piston being supposed to be at the top of the cylinder (fig. 18.) and the rod E raised, the valves A and D are opened, and B and C closed. The steam enters from the steam-pipe at an aperture immediately above the valve A, and passing through the open valve, enters the cylinder above the piston. At the same time, the steam which is below the piston, and which has just pressed it up, flows through the open valve D, and through a tube immediately under it to the condenser. A vacuum being thus produced below the piston, and steam pressure acting above it, it descends, and when it arrives at the bottom of the cylinder (fig. 19.) the rod E is permitted to fall, and the valves A and D fall into their seats, and at the same time the rod F is raised, and the valves B and C are opened. Steam now is admitted through an

aperture above the valve C, and passes below the piston, while the steam above it passes through the open valve B into a tube immediately under it, which leads to the condenser. A vacuum being thus produced above the piston, and steam pressure acting below it, the piston ascends, and thus the alternate ascent and descent is continued by the motion communicated to the rods E F from the fly-wheel.

(64.) There are various other contrivances for regulating the circulation of steam through the cylinder. In fig. 22. 23. is represented a section of a slide valve suggested by Mr. Murray of Leeds. The steam-pipe from the boiler enters the valve-box D E at S. Curved passages A A, B B, communicate between this valve-box and the top and bottom of the cylinder; and a fourth passage leads to the tube C, which passes to the condenser. A sliding piece within the valve-box opens a communication alternately between each end of the cylinder, and the tube C which leads to the condenser. In the position of the apparatus in fig. 22. steam is passing from the steam-pipe S, through the curved passage A A above the piston, and at the same time the steam below the piston is passing through the passage B B into the tube C, and thence to the condenser. A vacuum is thus formed below the piston, and steam is introduced above it. The piston, therefore, descends; and when it arrives at the bottom of the cylinder, the slide is moved into the position represented in fig. 23. Steam now passes from S through B B below the piston, and the steam above it passes through A A and C to the condenser.

A vacuum is thus produced above the piston, and steam pressure is introduced below it, and the piston ascends; and in this way the motion is continued.

The slide is moved by a lever, which is worked by the eccentric from the fly-wheel.

(65.) Watt suggested a method of regulating the circulation of steam, which is called the D valve, from the resemblance which the horizontal section of the valve has to the letter D. This method, which is very generally used, is represented in section in fig. 24. 25. Steam from the boiler enters through s. A rod of metal connects two solid plugs A B, which move steam-tight in the passage D. In the position of the apparatus represented in fig. 24. the steam passes from s through the passage D, and enters the cylinder above the piston, while the steam below the piston passes through the open passage by the tube C to the condenser. A vacuum is thus formed below the piston, while the pressure of steam is introduced above it, and it accordingly descends. When it has arrived at the bottom of the cylinder, the plugs A B are moved into the position in fig. 25. Steam now passing from s through D, enters the cylinder below the piston; while the steam which is above the piston, and has just pressed it down, passes through the open passage into the condenser. A vacuum is thus produced above the piston, and the steam pressure below forces it up. When it has arrived at the top of the cylinder, the position of the plugs A B is again changed to that represented in fig. 24. and a similar effect to that already described

is produced, and the piston is pressed down; and so the process is continued.

The plugs A B, and the rod which connects them, are moved up and down by proper levers, which receive their motion from the eccentric.

This contrivance is frequently modified, particularly in cases where the engine is not of very great power, by conducting the steam from above the piston to the condenser, through a tube in the plugs A B, and their connecting rod. In fig. 26. 27. a tube passes through the plugs A B and the rod which joins them. In the position fig. 26. steam entering at S, passes through the tube to the cylinder above the piston, while the steam below the piston passes through C into the condenser. A vacuum being thus made below the piston, and steam pressing above it, it descends; and when it has arrived at the bottom of the cylinder, the position of the plugs A B and tube is changed to that represented in fig. 27. The steam now entering at S passes to the cylinder below the piston, while the steam above the piston passes through C into the condenser. A vacuum is thus produced above the piston, and steam pressure introduced below it, so that it ascends. When it has arrived at the top of the cylinder, the plugs are moved into the position represented in fig. 26. and similar effects being produced, the piston again descends; and so the motion is continued.

The motion of the sliding tube may be effected like the former contrivances, by the action of the eccentric. It is also sometimes done by a bracket fastened on the piston-rod. This bracket, in the de-

scent of the piston, strikes a projection on the valve-rod, and drives it down, and in the ascent meets a similar projection, and raises it.

(66.) Another method, worthy of notice for its elegance and simplicity, is the *four-way cock*. A section of this contrivance is given in fig. 28. 29. C T S B are four passages or tubes; S leads from the boiler, and introduces steam; C, opposite to it, leads to the condenser; T is a tube which communicates with the top of the cylinder; and B one which communicates with the bottom of the cylinder. These four tubes communicate with a cock which is furnished with two curved passages, as represented in the figures; and these passages are so formed, that according to the position given to the cock, they may be made to open a communication between any two adjacent tubes of the four just mentioned. When the cock is placed as in fig. 28. communication is opened between the steam-pipe and the top of the cylinder by one of the curved passages, and between the condenser and the bottom of the cylinder by the other curved passage. In this case the steam passes from below the piston to the condenser, leaving a vacuum under it, and steam is introduced from the boiler above the piston. The piston therefore descends; and when it has arrived at the bottom of the cylinder, the position of the cock is changed to that represented in fig. 29. This change is made by turning the cock through one fourth of an entire revolution, which may be done by a lever moved by the eccentric, or by various other means. One of the curved passages in the cock now

opens a communication between the steam-pipe and the bottom of the cylinder; while the other opens a communication between the condenser and the top of the cylinder. By these means, the steam from the boiler is introduced below the piston, while the steam above the piston is drawn off to the condenser. A vacuum being thus made above the piston, and steam introduced below it, it ascends; and when it has arrived at the top of the cylinder, the cock being moved back, it resumes the position in fig. 28. and the same consequences ensue, the piston descends, and so the process is continued. In fig. 30. 31. the four-way cock with the passages to the top and bottom of the cylinder is represented on a larger scale.

This beautiful contrivance is not of late invention. It was used by Papin, and is also described by Leupold in his *Theatrum Machinarum*, a work published about the year 1720, in which an engine is described acting with steam of high pressure, on a principle which we shall describe in a subsequent lecture.

The four-way cock is liable to some practical objections. The quantity of steam which fills the tubes between the cock and the cylinder, is wasted every stroke. This objection, however, also applies to the sliding valve (fig. 22. 23.) and to the sliding tube or D valves (fig. 24. 25. 26. 27.) In fact, it is applicable to every contrivance in which means of shutting off the steam are not placed at both top and bottom of the cylinder. Besides this, however, the various passages and tubes cannot be conveniently made large enough to supply steam in sufficient abundance, and consequently it becomes necessary to pro-

duce steam in the boiler of a more than ordinary strength to bear the attenuation which it suffers in its passage through so many narrow tubes.

One of the greatest objections, however, to the use of the four-way cock, particularly in large engines, is its unequal wear. The parts of it near the passages having smaller surfaces, become more affected by the friction, and in a short time the steam leaks between the cock and its case, and becomes wasted, and tends to vitiate the vacuum. These cocks are, therefore, seldom used, except in small condensing engines; but are almost universally adopted in high-pressure steam-engines; for in these the leakage is not of so much consequence, as will appear hereafter.

LECTURE VIII.

The Boiler and its Appendages — Level Gauges — Feeding Apparatus — Steam Gauge — Barometer Gauge — Safety Valves — Self-regulating Damper — Edelcrantz's Valve — Furnace — Smoke-consuming Furnace — Brunton's Self-regulating Furnace — Oldham's Modification.

(67.) THE regular action of a steam-engine, as well as the economy of fuel, depends in a great degree on the construction of the boiler or apparatus for generating the steam. The boiler may be conceived as a great magazine of steam for the use of the engine; and care must be taken not only that a sufficient quantity be always ready for the supply of the machine, but also that it shall be of the proper quality, that is, that its pressure shall not exceed that which is required, nor fall short of it. Precautions should be, therefore, taken, that the production of steam should be exactly proportioned to the work to be done, and that the steam so produced shall be admitted to the cylinder in the same proportion.

To accomplish this, various contrivances, eminently remarkable for their ingenuity, have been resorted to, and which we shall now proceed to describe.

(68.) Different methods have been, from time to time, suggested for indicating the level of the water in the boiler. We have already mentioned the two gauge-pipes used in the earlier steam-engines (25); and which are still in many cases continued. There are, however, some other methods which merit our attention.

A weight F (fig. 32.) half immersed in the water in the boiler, is supported by a wire, which, passing steam-tight through a small hole in the top, is connected by a flexible string or chain passing over a wheel W, with a counterpoise A, which is just able to balance F, when half immersed. If F be raised above the water, A, being lighter, will no longer balance it, and F will descend, pulling up A, and turning the wheel W. If, on the other hand, F be plunged deeper in the water, A will more than balance it, and will pull it up. So that the only position in which F and A will balance each other is when F is half immersed. The wheel W is so adjusted, that when two pins, placed on its rim, are in the horizontal position, as in fig. 32. the water is at its proper level. Consequently it follows, that if the water rises above this level, the weight F is lifted, and A falls, so that the pins P P′ come into the position in fig. 33. If, on the other hand, the level of the water falls, F falls and A rises, so that the pins P P′ assume the position in fig. 34. Thus, in general, the position of the pins P P′ becomes an indication of the quantity of water in the boiler.

Another method is to place a glass tube (fig. 35.) with one end T entering the boiler above the proper

level, and the other end r′ entering it below the proper level. It must be evident that the water in this tube will always stand at the same level as the water in the boiler; since the lower part has a free communication with that water, while the suface is submitted to the pressure of the same steam as the water in the boiler. This, and the last-mentioned gauge have the advantage of addressing the eye of the engineer at once, without any adjustment, whereas the gauge cocks (25) must be both opened, whenever the depth is to be ascertained.

These gauges, however, require the frequent attention of the engine man; and it becomes desirable either to find some more effectual means of awakening that attention, or to render the supply of the boiler, independent of any attention. In order to enforce the attention of the engine man, to replenish the boiler when partially exhausted by evaporation, a tube was sometimes inserted at the lowest level to which it was intended that the water should be permitted to fall. This tube was conducted from the boiler into the engine-house, where it terminated in a mouth-piece or whistle, so that whenever the water fell below the level at which this tube was inserted in the boiler, the steam would rush through it, and issuing with great velocity at the mouth-piece, would summon the engineer to his duty with a call that would rouse him even from sleep.

(69.) In the most effectual of these methods, the task of replenishing the boiler should still be executed by the engineer; and the utmost that the boiler itself was made to do, was to give due notice

of the necessity for the supply of water. The consequence was, among other inconveniences, that the level of the water was subject to constant variation.

To remedy this, a method has been invented by which the engine is made to feed its own boiler. The pipe G′ (fig. 15.), which leads from the hot water pump H′, terminates in a small cistern C (fig. 36.), in which the water is received. In the bottom of this cistern a valve V is placed, which opens upwards, and communicates with a feed-pipe, which descends into the boiler below the level of the water in it. The stem of the valve V is connected with a lever turning on the centre D, and loaded with a weight F dipped in the water in the boiler in a manner similar to that described in fig. 32. and balanced by a counterpoise A in exactly the same way. When the level of the water in the boiler falls, the float F falls with it, and pulling down the arm E of the lever, raises the valve V, and lets the water descend into the boiler from the cistern C. When the boiler has thus been replenished, and the level raised to its former place, F will again be raised, and the valve V closed by the weight A. In practice, however, the valve V adjusts itself by means of the effect of the water on the weight F, so as to permit the water from the feeding cistern C to flow in a continued stream, just sufficient in quantity to supply the consumption from evaporation, and to maintain the level of the water in the boiler constantly the same.

By this singularly felicitous arrangement, the boiler is made to replenish itself, or, more properly speaking, it is made to receive such a supply as that it never wants replenishing, an effect which no effort

of attention on the part of an engine-man could produce. But this is not the only good effect produced by this contrivance. A part of the steam which originally left the boiler, and having discharged its duty in moving the piston, was condensed and reconverted into water, and lodged by the air-pump in the hot-well (47), is here again restored to the source from which it came, bringing back all the unconsumed portion of its heat preparatory to being once more put in circulation through the machine.

The entire quantity of hot water pumped into the cistern C is not always required for the boiler. A waste-pipe may be provided for carrying off the surplus, which may be turned to any purpose for which it may be required; or it may be discharged into a cistern to cool, preparatory to being restored to the cold cistern (fig. 12.), in case water for the supply of that cistern be not sufficiently abundant.

In cities and places in which it becomes an object to prevent the waste of water, the waste-pipes, proceeding from the feed-cistern C (fig. 36), and from the cold cistern containing the condenser and air-pump, may be conducted to a cistern A B (fig. 37.) Let C be the pipe from the feeding cistern, and D that from the cold cistern; by these pipes the waste water from both these cisterns is deposited in A B. In the bottom of A B is a valve V, opening upwards, connected with a float F. When the quantity of water collected in the cistern A B is such, that the level rises considerably, the float F is raised, and lifts the valve V, and the water flows into the main-pipe, which supplies water for working the en-

gine. G is the cold water-pump for the supply of the cold cistern.

This arrangement for saving the water discharged from the feeding and condensing cisterns has been adopted in the printing office of the Bank of Ireland, and a very considerable waste of water is thereby prevented.

(70.) It is necessary to have a ready method of ascertaining at all times the strength of the steam which is used in working the engine. For this purpose a bent tube containing mercury is inserted into some part of the apparatus which has free communication with the steam. It is usually inserted in the *jacket* of the cylinder (44). Let A B C (fig. 38.) be such a tube. The pressure of the steam forces the mercury down in the leg A B, and up in the leg B C. If the mercury in both legs be at exactly the same level, the pressure of the steam must be exactly equal to that of the atmosphere; because the steam pressure on the mercury in A B balances the atmospheric pressure on the mercury in B C. If, however, the level of the mercury in B C be above the level of the mercury in B A, the pressure of the steam will exceed that of the atmosphere. The excess of its pressure above that of the atmosphere may be found by observing the difference of the levels of the mercury in the tubes B C and B A; allowing a pressure of one pound on each square inch for every two inches in the difference of the levels.

If, on the contrary, the level of the mercury in B C should fall below its level in A B, the atmospheric

pressure will exceed that of the steam, and the degree or quantity of the excess may be ascertained exactly in the same way.

If the tube be glass, the difference of levels of the mercury would be visible; but it is most commonly made of iron; and in order to ascertain the level, a thin wooden rod with a float, is inserted in the open end of B C; so that the portion of the stick within the tube indicates the distance of the level of the mercury from its mouth. A bulb or cistern of mercury might be substituted for the leg A B, as in the common barometer. This instrument is called the *steam-gauge.*

If the steam-gauge be used as a measure of the strength of the steam which presses on the piston, it ought to be on the same side of the throttle valve (which is regulated by the governor) as the cylinder; for if it were on the same side of the throttle valve with the boiler, it would not be affected by the changes which the steam may undergo in passing through the throttle valve, when partially closed by the agency of the governor. (61)

(71.) The force with which the piston is pressed depends on two things: 1°, the actual strength of the steam which presses on it; and 2°, on the actual strength of the vapour which resists it. For, although the vacuum produced by the method of separate condensation be much more perfect than what had been produced in the atmospheric engines, yet still some vapour of a small degree of elasticity is found to arise from the hot water in the bottom of

the condenser, before it can be extracted by the air-pump. One of these pressures is indicated by the steam-gauge already described; but still, before we can estimate the force with which the piston descends, it is necessary to ascertain the force of the vapour which remains uncondensed, and resists the motion of the piston. Another gauge, called the barometer-gauge, is provided for this purpose. A glass tube A B (fig. 39.), more than thirty inches long, and open at both ends, is placed in an upright or vertical position, having the lower end B immersed in a cistern of mercury, C. To the upper end is attached a metal tube, which communicates with the condenser, in which a constant vacuum, or, rather, high degree of rarefaction is sustained. The same vacuum must, therefore, exist in the tube A B, above the level of the mercury; and the atmospheric pressure on the surface of the mercury in the cistern C will force the mercury up in the tube A B, until the column which is suspended in it is equal to the difference between the atmospheric pressure, and the pressure of the uncondensed steam. (6) The difference between the column of mercury sustained in this instrument and in the common barometer, will determine the strength of the uncondensed steam, allowing a force proportional to one pound per square inch for every two inches of mercury in the difference of the two columns. (6) In a well-constructed engine, which is in good order, there is very little difference between the altitude in the barometer gauge and the common barometer.

To compute the force with which the piston descends, thus becomes a very simple arithmetical process. First ascertain the difference of the levels of the mercury in the steam-gauge. This gives the excess of the steam pressure above the atmospheric pressure. Then find the height of the mercury in the barometer gauge. This gives the excess of the atmospheric pressure above the uncondensed steam. Hence, if these two heights be added together, we shall obtain the excess of the impelling force of the steam from the boiler on the one side of the piston above the resistance of the uncondensed steam on the other side. This will give the effective impelling force. Now, if one pound be allowed for every two inches of mercury in the two columns just mentioned, we shall have the number of pounds of impelling pressure on every square inch of the piston. Then if the number of square inches in the section of the piston be found (p. 44, note), and multiplied by the number of pounds on each square inch, the whole effective force with which it moves will be obtained.

In the computation of the power of the engine, however, all this force, thus computed, is not to be allowed as the effective working power. For it requires some force, and by no means an inconsiderable portion, to move the engine itself, even when unloaded; all this, therefore, which is spent in overcoming friction, &c. is to be left out of account, and only the balance set down as the effective working power.

From what we have stated, it appears that in order to estimate the effective force with which the piston

is urged, it is necessary to refer to both the barometer and the steam gauge. This double computation may be obviated by making one gauge serve both purposes. If the end C of the steam gauge (fig. 38), instead of communicating with the atmosphere, were continued to the condenser, we should have the pressure of the steam acting upon the mercury in the tube B A, and the pressure of the uncondensed vapour which resists the piston acting on the mercury in the tube B C. Hence the difference of the levels of the mercury in the tubes will at once indicate the difference between the force of the steam and that of the uncondensed vapour, which is the effective force with which the piston is urged.

(71.) To secure the boiler from accidents arising from the steam becoming too strong, a safety valve is used, similar to those described in Papin's steam-engine (40), loaded with a weight equal to the strength which the steam is intended to have above the atmospheric pressure; for it is found expedient, even in condensing engines, to use the steam of a pressure somewhat above that of the atmosphere.

Besides this valve, another of the very opposite kind is sometimes used. Upon stopping the engine, and extinguishing the fire, it is found that the steam, condensed within the boiler, produces a vacuum; so that the atmosphere, pressing on the external surface of the boiler, has a tendency to crush it. To prevent this, a safety valve is provided, which opens inwards, and which being forced open by the atmospheric pressure when a vacuum is produced within, the air

rushes in, and a balance is obtained between the pressures within and without.

(72.) We have already explained the manner in which the governor regulates the supply of steam from the boiler to the cylinder, proportioning the quantity to the work to be done, and thereby sustaining an uniform motion. Since, then, the *consumption* of steam in the engine is subject to variation, owing to the various quantities of work it may have to perform, it is evident that the *production* of steam in the boiler should be subject to a proportional variation. For, otherwise, one of two effects would ensue: the boiler would either fail to supply the engine with steam, or steam would accumulate in the boiler, from being produced in too great abundance, and would escape at the safety-valve, and thus be wasted. In order, to vary the production of steam in proportion to the demands of the engine, it is necessary to increase or mitigate the furnace, as production is to be augmented or diminished. To effect this by any attention on the part of the engine-man would be impossible; but a most ingenious method has been contrived, of making the boiler regulate itself in these respects. Let T (fig. 40.) be a tube inserted in the top of the boiler, and descending nearly to the bottom. The pressure of the steam on the surface of the water in the boiler forces water up in the tube T, until the difference of the levels is equal to the difference between the pressure of steam in the boiler and that of the atmosphere. A weight F, half immersed in the water in the tube, is suspended by

a chain which passes over the wheels P P′, and is balanced by a metal plate D, in the same manner as the float in fig. 32. is balanced by the weight A. The plate D passes through the mouth of the flue E, as it issues finally from the boiler; so that when the plate D falls, it stops the flue, and thereby suspends the draught of air through the furnace, mitigates the fire, and diminishes the production of steam. If, on the contrary, the plate D be drawn up, the draught is increased, the fire rendered more effective, and the production of steam in the boiler stimulated. Now suppose that the boiler is producing steam faster than the engine consumes it, either because the load on the engine has been diminished, and therefore its consumption of steam proportionally diminished, or because the fire has become too intense. The consequence is, that the steam beginning to accumulate, will press upon the surface of the water in the boiler with increased force, and the water will rise in the tube T. The weight F will therefore be lifted, and the plate D will descend, stop the draught, mitigate the fire, and check the production of steam; and it will continue so to do, until the production of steam becomes exactly equal to the demands of the engine.

If, on the other hand, the production of steam be not equal to the wants of the machine, either because of the encreased load, or the insufficiency of the fire, the steam in the boiler losing its elasticity, the surface of the water rises, not sustaining a pressure sufficient to keep it at its wonted level. Therefore, the surface in the tube T falls, and the weight F falls, and the plate D rises. The draught is thus

increased, by opening the flue, and the fire rendered more intense; and thus the production of steam is stimulated, until it is sufficiently rapid for the purposes of the engine. This apparatus is called the *self-acting damper.*

(73.) It has been proposed to connect this damper with a safety-valve invented by the Chevalier Edelcrantz. A small brass cylinder is fixed to the boiler, and is fitted with a piston which moves in it, without much friction, and nearly steam-tight. The cylinder is closed at top, having a hole through which the piston-rod plays; so that the piston is thus prevented from being blown out of the cylinder by the steam. The side of the cylinder is pierced with small holes opening into the air, and placed at short distances above each other. Let the piston be loaded with a weight proportional to the pressure of the steam intended to be produced. When the steam has acquired a sufficient elasticity, the piston will be lifted, and steam will escape through the first hole. If the production of steam be not too rapid, and that its pressure be not increasing, the piston will remain suspended in this manner; but if it increase, the piston will be raised above the second hole, and it will continue to rise until the escape of the steam through the holes is sufficient to render the weight of the piston a counterpoise for the steam. This safety-valve is particularly well adapted to cases where steam of an exactly uniform pressure is required; for the pressure must necessarily be always equal to the weight on the piston. Thus, suppose the section of the

piston be equal to a square inch; if it be loaded with 10lbs, including its own weight, the steam which will sustain it in any position in the cylinder, whether near the bottom or top, must always be exactly equal in pressure to 10lbs. per inch. In this respect it resembles the quality already explained in the governor, and renders the pressure of the steam uniform, exactly in the same manner as the governor renders the velocity of the engine uniform.

(74.) The economy of fuel depends, in a great degree on the construction of the furnace, independently of the effects of the arrangements we have already described.

The grate or fire-place of an ordinary furnace is placed under the boiler; and the atmospheric air passing through the ignited fuel, supplies sufficient oxygen to support a large volume of flame, which is carried by the draught into a flue which circulates twice or oftener round the boiler, and in immediate contact with it, and finally issues into the chimney. Through this flue the flame circulates, so as to act on every part of the boiler near which the flue passes; and it is not until it passes into the chimney, and frequently not until it leaves the chimney that it ceases to exist in the state of flame.

The dense black smoke which is observed to issue from the chimneys of furnaces is formed of a quantity of unconsumed fuel, and may be therefore considered as so much fuel wasted. Besides this, in large manufacturing towns, where a great number of furnaces are employed, it is ound that the quantity

of smoke which thus becomes diffused through the atmosphere, renders it pernicious to the health, and destructive to the comforts of the inhabitants.

These circumstances have directed the attention of engineers to the discovery of means whereby this smoke or wasted fuel may be consumed for the use of the engine itself, or for whatever use the furnace may be applied to. The most usual method of accomplishing this, is by arranging matters so that fuel in a state of high combustion, and, therefore, producing no smoke, shall be always kept on that part of the grate which is nearest to the mouth of the the flue (and which we shall call the back); by this means the smoke which arises from the imperfectly ignited fuel which is nearer to the front of the grate, must pass over the surface of the red fuel, before it enters the flue, and is thereby ignited, and passes in a state of flame into the flue. A passage called the *feeding-mouth* leads to the front of the grate, and both this passage and the grate are generally inclined at a small angle to the horizon in order to facilitate the advance of the fuel according as its combustion proceeds.

When fresh fuel for feeding the boiler is first introduced, it is merely laid in the feeding-mouth. Here it is exposed to the action of a part of the heat of the burning fuel on the grate, and undergoes, in some degree, the process of coking. The door of the feeding-mouth is furnished with small apertures fo the admission of a stream of air, which carries the smoke, evolved by the coking of the fresh fuel over the burning fuel on the grate, by which this smoke is

ignited, and becomes flame, and in this state enters the flue, and circulates round the boiler. When the furnace is to be fed, the door of the feeding mouth is opened, and the fuel which had been laid in it, and partially coked, is forced upon the front part of the grate. At first, its combustion being imperfect, but proceeding rapidly, a dense black smoke arises from it. The current of air from the open door through the feeding mouth, carries this over the vividly burning fuel, in the back part of the grate, by which the smoke being ignited, passes in a state of flame into the flue. When the furnace again requires feeding, every part of this fuel will be in a state of active combustion, and it is forced to the back part of the grate next the flue, preparatory to the introduction of more fuel from the feeding mouth.

The apertures in the door of the feeding-mouth are furnished with covers, so that the quantity of air admitted through them can be regulated by the workmen. The efficiency of these furnaces in a great degree depends on the judicious admission of the air through the feeding-mouth: for if less than the quantity necessary to support the combustion of the fuel be admitted, a part of the smoke will remain unconsumed, and if more than the proper quantity be admitted, it will defeat the effects of the fuel by cooling the boiler. If the process which we have just described be considered, it will not be difficult to perceive the total impossibility in such a furnace, of exactly regulating the draught of air, so that too much shall not pass at one time, and too little at another. When the door is open to introduce fresh

fuel into the feeding-month, and advance that which occupied it upon the grate, the workman ceases to have any controul whatever over the draught of air; and even at other times when the door is closed, his discretion and attention cannot be depended on. The consequence is, that with these defects the proprietors of steam-engines found, that in place of economising the fuel, the use of these furnaces entailed on them such an increased expense, that they were generally obliged to lay them aside.

(75.) Mr. Brunton of Birmingham having turned his attention to the subject, has produced a furnace which seems to be free from the objections against those we have just mentioned. The advantages of his contrivance, as stated by himself, are as follow:

"First, I put the coal upon the grate by small quantities, and at very short intervals, say every two or three seconds: 2ndly, I so dispose of the coals upon the grate, that the smoke evolved must pass over that part of the grate upon which the coal is in full combustion, and is thereby consumed; 3rdly, as the introduction of the coal is uniform in short spaces of time, the introduction of the air is also uniform, and requires no attention from the fireman.

"As it respects economy: 1st, the coal is put upon the fire by an apparatus driven by the engine, and so contrived that the quantity of coal is proportioned to the quantity of work which the engine is performing, and the quantity of air admitted to consume the smoke is regulated in the same manner; 2ndly, the fire door is never opened, excepting to clean the fire;

the boiler of course is not exposed to that continual irregularity of temperature which is unavoidable in the common furnace, and which is found exceedingly injurious to boilers; 3rdly, the only attention required is to fill the coal receiver, every two or three hours, and clean the fire when necessary; 4thly, the coal is more completely consumed than by the common furnace, as all the effect of what is termed stirring up the fire (by which no inconsiderable quantity of coal is passed into the ash-pit) is attained without moving the coal upon the grate."

The fire-place is a circular grate placed on a vertical shaft in an horizontal position. It is capable of revolving, and is made to do so by the vertical shaft, which is turned by wheel-work, which is worked by the engine itself; or this shaft or spindle may be turned by a water-wheel, on which a stream of water is allowed to flow from a reservoir, into which it is pumped by the power of the engine; and by regulating the quantity of water in the stream, the grate may be made to revolve with a greater or lesser speed. In that part of the boiler which is over the grate, there is an aperture in which is placed a hopper, through which fuel is let down upon the grate at the rate of any quantity per minute that may be required. The apparatus which admits the coals through this hopper is worked by the engine also, and, by the same means as the grate, is turned so that the grate revolves with a speed proportional to the rapidity with which the fuel is admitted through the hopper, and by this ingenious arrangement, the fuel falls equally thick upon the grate.

The supply of water which turns the wheel which works the grate and the machinery in the hopper, is regulated by a cock connected with the self-regulating damper, so that when the steam is being produced too fast, the supply of water will be diminished; and by that means the supply of fuel to the grate will be diminished, and the grate will revolve less rapidly; and when the steam is being produced too slowly for the demands of the engine, the contrary effects take place. In this way the fuel which is introduced into the furnace is exactly proportioned to the work which the engine has to perform. The hopper may be made large enough to hold coals for a day's work, so that the furnace requires no other attendance than to deposite coals in the hopper each morning.

The coals are let down from the hopper on the grate at that part which is most remote from the flue, and as they descend in very small quanties at a time, they are almost immediately ignited. But until their ignition is complete, a smoke will arise, which, passing to the flue over the vividly burning fuel, will be ignited. Air is admitted through proper apertures, and its quantity regulated by the damper in the same manner as the supply of fuel.

The superiority of this beautiful invention over the common smoke-consuming furnaces is very striking. Its principle of self-adjustment as to the supply of coals and atmospheric air, and the proportioning of these to the quantity of work to be performed by the engine, not only independent of human labor, but with a greater degree of accuracy than any human skill or attention could possibly effect, produces an extensive saving of expense, both in fuel and labor.

Mr. Partington states that the effect of the self-regulating furnace, as compared with the common furnace, has been ascertained by direct experiment at the Old Union Mill, Birmingham, and at the distillery of Messrs. Liptrap and Smith, Whitechapel, London. The results of these experiments were as follow:

At the Old Union Mill, nine days' experiment—

Common furnace consumed....	465 cwt.
Regulating furnace	290 cwt.
Saving	175 cwt.

At the White-chapel distillery, eighteen days' experiment —

Common furnace consumed....	284 cwt.
Regulating furnace	194 cwt.
Saving	90 cwt.

From which it appears that the saving in the first case is about 37 per cent, and in the second but very little less.

(76.) Mr. Oldham, engineer to the Bank of Ireland, has proposed another modification of the self-regulating furnace, which seems to possess several advantages, and evinces considerable ingenuity.

He uses a slightly inclined grate, at the back or lower end of which is the flue, and at the front or higher end, the hopper for admitting the coals. In the bottom or narrow end of the hopper is a moveable shelf worked by the engine. Upon drawing back this shelf, a small quantity of fuel is allowed to de-

scend upon a fixed shelf under it; and upon the return of the moveable shelf this fuel is protruded forward upon the grate. Every alternate bar of the grate is fixed, but the intermediate ones are connected with levers, by which they are moved alternately up and down.* The effect is, that the coals upon the bars are continually stirred, and gradually advanced by their own weight from the front of the grate where they fall from the hopper, to the back, where they are deposited in the ash-pit. By the shape and construction of the bars, the air is conducted upwards between them, and rushes through the burning fuel, so as to act, as Mr. Oldham states, in the manner of a blow-pipe, and the entire surface of the fire presents a sheet of flame.

We cannot fail to be struck with the beauty of all these contrivances, by which the engine is made to regulate itself, and to supply its own wants. It is, in fact, all but alive. It was observed by Belidor, long before the steam-engine reached the perfection which it has now acquired, that it strongly resembled an animal, and that no mere work of man ever approached so near to actual *life*. Heat is the principle of its existence. The boiler acts the part of the heart from which its vivifying fluid rushes copiously through all the tubes, where having discharged the various func-

* Mr. Brunton used moveable bars in a furnace constructed by him before he adopted the horizontal revolving grate. That plan, however, does not appear to have been as successful as the latter, as he has abandoned it. Mr. Oldham states that his furnace has been in use for three years without any appearance of derangement in the mechanism, and with a considerable saving of fuel.

tions of life, and deposited its heat in the proper places, returns again to the source it sprung from, to be duly prepared for another circulation. The healthfulness of its action is indicated by the regularity of its pulsations; it procures its own food by its own labor; it selects those parts which are fit for its support, both as to quantity and quality, and has its natural evacuations, by which all the useless and unnutritious parts are discharged. It frequently cures its own diseases, and corrects the irregularity of its own actions, exerting something like physical and moral faculties. Without designing to carry on the analogy, Mr. Farey, in speaking of the variations incident to the work performed by different steam-engines, states some further particulars in which it may be curiously extended. "We must observe" says he "that the variation in the performance of different steam-engines, which are constructed on the same principle, working under the same advantages, is the same as would be found in the produce of the labor of so many different horses or other animals when compared with their consumption of food; for the effects of different steam-engines will vary as much from small differences in the proportion of their parts, as the strength of animals from the vigor of their constitutions; and again there will be as great differences in the performance of the same engine when in good and bad order, from all the parts being tight and well oiled, so as to move with little friction, as there is in the labor of an animal from his being in good or bad health or excessively fatigued; but in all these cases will be a maximum which cannot be exceeded, and an average which we ought to expect to obtain."

LECTURE IX.

Double Cylinder Engines — Hornblower's Engine — Woolf's Engine — Cartwright's Engine.

(77.) THE expansive property of steam, of which Watt availed himself in his single engine by cutting off the supply of steam before the descent of the piston was completed, was applied in a peculiar manner by an engineer named Hornblower, about the year 1781, and at a later period by Woolf. Hornblower was the first who conceived the idea of working an engine with two cylinders of different sizes, by allowing the steam to flow freely from the boiler until it fills the smaller cylinder, and then permitting it to expand into the greater one, employing it thus to press down two pistons in the manner which we shall presently describe. The condensing apparatus of Hornblower, as well as the other appendages of the engine, do not differ materially from those of Watt; so that it will be sufficient for our present purpose, to explain the manner in which the steam is made to act in moving the piston.

Let c, fig. 41, be the centre of the great working

beam carrying two arch heads, on which the chains of the piston rods play. The distances of these arch heads from the centre C must be in the same proportion as the length of the cylinders, in order that the same play of the beam may correspond to the plays of both pistons. Let F be the steam-pipe from the boiler, and G be a valve to admit the steam above the lesser piston. H is a tube by which a communication may be opened by the valve I between the top and bottom of the lesser cylinder B, K is a tube communicating by the valve L between the bottom of the lesser cylinder B, and the top of the greater cylinder A. M is a tube communicating by the valve N between the top and bottom of the greater cylinder A; and P a tube leading to the condenser by the exhausting valve O.

At the commencement of the operation, suppose all the valves opened, and steam allowed to flow through the entire engine until the air be completely expelled, and then let all the valves be closed. To start the engine, let the exhausting valve O, and the steam valves F and L be opened as in fig. 41. The steam will flow freely from the boiler, and press upon the lesser piston, and at the same time the steam below the greater piston will flow into the condenser, leaving a vacuum in the greater cylinder. The valve L being opened, the steam which is under the piston in the lesser cylinder will flow through K, and press on the greater piston, which having a vacuum beneath it, will consequently descend. At the commencement of the motion, the lesser piston is as much resisted by the steam below it, as it is urged by the

steam above it; but after a part of the descent has been effected, the steam below the lesser piston passing into the greater, expands into an increased space, and therefore loses its elastic force proportionally. The steam abbve the lesser piston retaining its full force by having a free communication with the boiler by the valve G, the lesser piston will be urged by a force equal to the excess of the pressure of this steam above the diminished pressure of the expanded steam below it. As the pistons descend, the steam which is between them is continually increasing in its bulk, and therefore decreasing in its pressure, from whence it follows that the force which resists the lesser piston is continually decreasing, while that which presses it down remains the same and therefore the effective force which impels it, must be continually increasing.

On the other hand the force which urges the greater piston is continually decreasing, since there is a vacuum below it, and the steam which presses it is continually expanding into an increased bulk.

Impelled in this way, let us suppose the pistons to have arrived at the bottoms of the cylinders as in fig. 42, and let the valves F, L and O, be closed, and the valves I and N opened. No steam is allowed to flow from the boiler F being closed, nor any allowed to pass into the condenser, since O is closed and all communication between the cylinders is stopped by closing L. By opening the valve I, a free communication is made between the top and bottom of the lesser piston through the tube H, so that the steam which presses above the lesser piston will exert the

atmospheric pressure below it, and the piston is in a state of indifference. In the meantime the valve N being open, a free communication is made between the top and bottom of the greater piston, and the steam circulates above and below the piston, and leaves it free to rise. A counterpoise attached to the pump-rods in this case, draws up the pistons as in Watt's single engine. And when they arrive at the top, the valves P and R are closed and F, L and O opened, and the next descent of the pistons is produced in the manner already described, and so the process is continued.

The valves are worked by the engine itself, by means similar to some of those already described. By computation, we find the power of this engine to be nearly the same as a similar engine on Watt's expansive principle. It does not however appear, that any adequate advantage has to be gained by this modification of the principle, since no engines of this construction are now made.

(78.) The use of two cylinders was revived by *Arthur Woolf*, in 1804, who, in this and the succeeding year, obtained patents for the application of steam raised under an high pressure to double cylinder engines. The specification of his patent states, that he has proved by experiment, that steam raised under a safety-valve loaded with any given number of pounds upon the square inch, will if allowed to expand into as many times its bulk as there are pounds of pressure on the square inch, have a pressure equal to that of the atmosphere. Thus, if the safety-valve be loaded with 4, 5, 6, or 10 lbs. on the square inch, it will have the atmospheric pressure when it has ex-

panded into 4, 5, 6, or 10 times its bulk, and so on.* It is, however, understood in this case, that the vessel into which it is thus allowed to expand, must have the same temperature as the steam before it expands.

Mr. Woolf's method of availing himself of the fact, which he thus alleges himself to have discovered, is as follows:

Two cylinders are provided: a larger, A, (fig. 43,) and a smaller, B, such, that A shall be as many times larger than B, as there are pounds weight avoirdupoise placed upon the safety-valve. Valves C C′ are placed at each end of the lesser cylinder, in tubes, communicating with the boiler, so as to admit steam on each side of the lesser piston, and cut it off at pleasure. A tube, D′, forms a communication between the upper end of the lesser, and lower end of the greater cylinder, and which communication is opened and closed at pleasure by the valve E′. In like manner, the tube D forms a communication between the lower end of the lesser cylinder, and the upper end of the greater, which may be opened and closed by the valve E. The top and bottom of the greater cylinder communicate with the condenser by valves F′ F.

Let us suppose that the air is blown from the engine in the usual way, and all the valves closed, and the engine ready to start, the pistons being at the top of the cylinders. Open the valves C, E and F. The steam which occupies the greater cylinder below the

* This is at variance with the known properties of elastic fluids, and there is no doubt, that Mr. Woolf has fallen into some error in deducing this conclusion from his observations and experiments.

piston, will now pass into the condenser through F, leaving a vacuum below the piston. The steam which is in the lesser cylinder below the piston will pass through D and the open valve E, and will press down the greater piston. The steam from the boiler will flow in at C, and press on the lesser piston. At first the whole motion will proceed from the pressure upon the greater piston since the steam both above and below the lesser piston, has the same pressure. But as the pistons descend, the steam below the less passing into the greater cylinder, expands into a greater space, and consequently exerts a diminished pressure, and, therefore, the steam on the other side exerting an undiminished pressure, acquires an impelling force exactly equal to the pressure lost in the expansion of the steam between the two pistons. Thus both pistons will be pressed to the bottoms of their respective cylinders. It will be observed that in the descent the greater piston is urged by a continually decreasing force, while the lesser is urged by continually increasing force.

Upon the arrival of the pistons at the bottoms of the cylinders, let the valves C, E, F be closed, and C′, E′, F′ be opened, as in fig. 44. The steam which is above the greater piston now flows through F′ into the condenser, leaving the space above the piston a vacuum. The steam which is above the lesser piston passes through E′ and D′ below the greater, while steam from the boiler is admitted through C′ below the lesser piston. The pressure of the steam entering through E′ below the greater piston pressing on it against the vacuum above it commences the ascent. In the mean time the steam above the lesser piston passing

into the enlarged space of the greater cylinder, loses gradually its elastic force, so that the steam entering from the boiler at c′ becomes in part effective, and the ascent is completed under the same circumstances exactly as the descent, and in this way the process is continued.

It is evident that the valves may be easily worked by the mechanism of the engine itself.

In this arrangement the pistons ascend and descend together, and their rods must consequently be attached to the beam at the same side of the centre. It is sometimes desirable that they should act on different sides of the centre of the beam, and consequently that one should ascend while the other descends. It is easy to arrange the valves so as to effect this. In fig. 45, the lesser piston is at the bottom of the cylinder, and the greater at the top. On opening the valves c′, E′ F′, a vacuum is produced below the greater piston, and steam flows from the lesser cylinder through E′ *above* the greater piston, and presses it down. At the same time steam being admitted from the boiler through c′ below the lesser piston, forces it up against the diminishing force of the steam above it, which expands into the greater cylinder. Thus as the greater piston descends the lesser ascends. When each has traversed its cylinder, the valves c′, E′, F′ being closed and C, E, F opened, the lesser piston will descend, and the greater ascend, and so on.

Woolf's engine differs from that of Hornblower in using steam of an high pressure, and in being a double-acting engine. It is stated by Mr. Farey that some of these engines, which have been erected in

Cornwall, perform with an evident saving of fuel. It does not, however, appear that they have to any extent superseded the steam-engines of Watt. There are some peculiarities in the boiler used by Woolf for generating steam of the high pressure required for his engines, but these engines are not in sufficiently general use to induce us to enter further upon the subject here.

In 1790 a patent was granted to the Rev. Mr. Cartwright, a gentleman well known for other mechanical inventions, for some improvements in the steam-engine. His contrivance is at once so elegant and simple, that although it has not obtained very general use, yet we cannot pass it over without notice.

The steam-pipe from the boiler is represented but off at B (fig. 46); T is a spindle-valve for admitting steam above the piston, and R is a spindle-valve in the piston; D is a curved pipe forming a communication between the cylinder and the condenser, which is of very peculiar construction. Cartwright proposed effecting the condensation without a jet, by exposing the steam to contact with a very large quantity of cold surface. For this purpose, he formed his condenser, by placing two cylinders nearly equal in size, one within the other, allowing the water of the cold cistern in which they were placed to flow through the inner cylinder, and to surround the outer one. Thus the thin space between the two cylinders formed the condenser.

The air-pump is placed immediately under the cylinder, and the continuation of the piston-rod works

its piston, which is solid and without a valve: F is the pipe from the condenser to the air-pump, through which the condensed steam is drawn off through the valve G on the ascent of the piston, and on the descent, this is forced through a tube into a hot well, H, for the purpose of feeding the boiler through the feed-pipe I. In the top of the hot well H is a valve which opens inwards, and is kept closed by a ball floating on the surface of the liquid. The pressure of the condensed air above the surface of the liquid in H forces it through I into the boiler. When the air accumulates in too great a degree in H, the surface of the liquid is pressed so low that the ball falls and opens the valve, and allows it to escape. The air in H, is that which is pumped from the condenser with the liquid, and which was disengaged from it.

Let us suppose the piston at the top of the cylinder; it strikes the tail of the valve T, and raises it, while the stem of the piston-valve R strikes the top of the cylinder, and is pressed into its seat. A free communication is at the same time open between the cylinder, below the piston and the condenser, through the tube D. The pressure of the steam thus admitted above the piston, acting against the vacuum below it, will cause its descent. On arriving at the bottom of the cylinder, the tail of the piston-valve R will strike the bottom, and it will be lifted from its seat, so that a communication will be opened through it with the condenser. At the same moment, a projecting spring, K, attached to the piston-rod, strikes the stem of the steam valve T, and presses it into its seat. Thus, while the further admission of steam is cut off, the steam above the piston flows into the con-

denser, and the piston being relieved from all pressure, is drawn up by the momentum of the fly-wheel, which continues the motion it received from the descending force. On the arrival of the piston again at the top of the cylinder, the valve T is opened and R closed, and the piston descends as before, and so the process is continued.

The mechanism by which motion is communicated from the piston to the fly-wheel is peculiarly elegant. On the axis of the fly-wheel is a small wheel with teeth, which work in the teeth of another larger wheel L. This wheel is turned by a crank, which is worked by a cross-piece attached to the end of the piston-rod. Another equal toothed wheel M, is turned by a crank, which is worked by the other end of the cross-arm attached to the piston-rod.

One of the peculiarities of this engine, is, that the liquid which is used for the production of steam in the boiler circulates through the machine without either diminution or admixture with any other fluid, so that the boiler never wants more feeding than what can be supplied from the hot-well H. This circumstance forms a most important feature in the machine, as it allows of ardent spirits being used in the boiler instead of water, which since they boil at low heats, promised a saving of half the fuel. The inventor even proposed, that the engine should be used as a still, as well as a mechanical power, in which case, the whole of the fuel would be saved.

In this engine, the ordinary method of rendering the piston steam tight, by oil or melted wax, or tallow poured upon it, could not be applied, since the steam above the piston must always have a free passage

through the piston-valve R. The ingenious inventor, therefore contrived a method of making the piston steam-tight in the cylinder, without oil or stuffing, and his method has since been adopted with success in Woolf's engines.

A ring of metal is ground into the cylinder, so as to fit it perfectly, and is then cut into four equal segments. The inner surface of this ring being slightly conical, another ring is ground into it, so as to fit it perfectly, and this is also cut into four segments, and one is placed within the other, but in such a manner, that the joints or divisions do not coincide. The arrangement of the two rings is represented in fig. 47. Within the inner ring are placed four springs which press the pieces outward against the sides of the cylinder, and are represented in the diagram. Four pairs of these rings are placed one over another, so that their joints do not coincide, and the whole is screwed together by plates placed at top and bottom. A vertical section of the piston is given in fig. 48.

One of the advantages of this piston, is, that the longer it is worked, the more accurately it fits the cylinder, so that, as the machine wears it improves.

LECTURE X.

High pressure Engines — Leupold's — Trevithick and Vivian's — Locomotive Application of them — Perkins's Experiments.

(80.) In the various modifications of the steam-engine which we have hitherto considered, the pressure introduced on one side of the piston derives its efficacy either wholly or partially from the vacuum produced by condensation on the other side. This always requires a condensing apparatus, and a constant and abundant supply of cold water. An engine of this kind, must therefore, necessarily have considerable dimensions and weight, and is inapplicable to uses in which a small and light machine only is admissible. If the condensing apparatus be dispensed with, the piston will always be resisted by a force equal to the atmospheric pressure, and the only part of the steam pressure which will be available as a moving power, is that part by which it exceeds the the atmospheric pressure. Hence, in engines which do not work by condensation, steam of a much higher pressure than that of the atmosphere is indispensably necessary, and such engines are therefore called *high pressure engines.*

We are not, however, to understand that every

steam-engine, in which steam is used of a pressure exceeding that of the atmosphere, is what is intended to be meant by an *high pressure engine;* for in the ordinary engines in common use, constructed on Watt's principle, the safety-valve is loaded with from 3 to 5 lbs. on the square inch; and in Woolf's engines, the steam is produced under a pressure of 40 lbs. on the square inch. These would therefore, be more properly called *condensing-engines* than *low pressure engines*, a term utterly inapplicable to those of Woolf. In fact, by *high pressure engines* is meant engines in which no vacuum is produced, and therefore, in which the piston works against a pressure equal to that of the atmosphere.

In these engines, the whole of the condensing apparatus, *viz.* the cold water cistern, condenser, air-pump, cold water pump, &c. are dispensed with, and nothing is retained except the boiler, cylinder, piston, and valves. Consequently, such an engine is small, light, and cheap. It is portable also, and may be moved, if necessary, along with its load, and is therefore well adapted to locomotive purposes.

High pressure engines were one of the earliest modifications of the steam-engine. The contrivance, which is obscurely described in the article already quoted, (23) from the Century of Inventions, is an high-pressure engine; for the power there alluded to, is the elastic force of steam operating against the atmospheric pressure. *Newcomen*, in 1705, applied the working-beam, cylinder, and piston to the atmospheric engine; and *Leupold*, about 1720, combined the working-beam and cylinder with the high pres-

sure principle of Lord Worcester, and produced the earliest high-pressure engine worked by a cylinder and piston. The following is a description of *Leupold's* engine:

A (fig. 49.) is the boiler, with the furnace beneath it; C C′, are two cylinders with solid pistons P P′ connected with the working-beams B B′, to which are attached the pump-rods R R′ of two forcing-pumps F F′, which communicate with a great force-pipe S; G is a *four-way cock* (66) already described. In the position in which it stands in the figure, the steam is issuing from below the piston P into the atmosphere, and the piston is descending by its own weight; steam from the boiler is at the same time pressing up the piston P′. with a force equal to the difference between the pressure of the steam, and that of the atmosphere. Thus the piston R of the forcing-pump is being drawn up, and the piston P′ is forcing the piston R′ down, and thereby forcing water into the force-pipe S. On the arrival of the piston P at the bottom of the cylinder C, and P′ at the top of the cylinder C′, the position of the cock is changed to that represented in fig. 50. The steam which has just pressed up the piston P′, is allowed to escape into the atmosphere, while the steam passing from the boiler below the piston P presses it up, and thus P ascends by the steam-pressure, and P′ descends by its own weight. By these means, the piston R is forced down, driving before it the water in the pump-cylinder into the force-pipe S, and the piston R′ is drawn up to allow the other pump-cylinder to be refilled; and so the process is continued.

A valve is placed in the bottom of the force-pipe s, to prevent the return of the water which has been forced into it.

(81.) In modern times the application of steam to land carriage has again directed the attention of engineers to the construction of high-pressure engines. In 1802, Messrs. *Trevithick* and *Vivian* constructed a double acting high-pressure engine, remarkable for its elegance and ingenuity, and at once portable and effective. "These engines," says Mr. Stuart, "are equally well adapted to every use to which those of Mr. Watt are at present exclusively applied, and with the most ordinary precaution they may be made as safe from accident as those called in contradistinction, low-pressure; indeed, notwithstanding their recent invention, the consequent want of experience in their management, and the operation of vulgar and absurd prejudices against their safety, they may now be considered the only formidable rivals to the condensing engine."

The boiler of this engine is a large cylinder of iron, a section of which by a plane through its axis is represented in fig. 51, A B. The fire is contained within the boiler in a cylindrical tube C D, which is surrounded on all sides with water. One side of this tube is flanched to the end or cover of the boiler, and is divided into two parts by the grate which extends across it. The upper half forms the fire-place and the lower half the ash-pit. The tube then forms the flue which extends from the end C, where the grate is placed to the other end D, and then returns along D E

and issues into the chimney at E. The flame is thus conducted through the water, so as to expose it to as much heat as possible.

The cylinder F is placed within the boiler, except a few inches at the upper end, where the four-way cock is placed for admitting and withdrawing the steam; H is a tube for conducting the steam which has worked the piston into the chimney. The upper end of the piston rod is connected with a cross bar, which is placed in a direction at right angles to the length of the boiler, and this bar is guided in its motion by sliding on two perpendicular iron rods, fixed to the boiler and parallel to each other. To the ends of this cross bar two connecting rods are jointed, the lower ends of which work two cranks fixed upon an axis extending across beneath the boiler and under the centre of the cylinder. This axis is supported in bearings made in the legs which support the boiler, and on it the fly-wheel is fixed. A large cog-wheel is placed upon this axis, which, being turned with the axis by the cranks, it communicates motion to other cog-wheels, and through them to any machinery which the engine is applied to move.

As the cock G stands in fig. 51, the steam is passing from the boiler above the piston, and steam is also passing from below the piston through the tube H into the chimney. The steam therefore which passes above the piston presses it down. When the piston has arrived at the bottom of the cylinder the cock assumes the position represented in fig. 52, so that the steam now passes from above the piston through

the tube H into the chimney, while steam also passes from the boiler below the piston, and the piston ascends, and so the process is continued. The four-way cock is worked by the engine itself.

It is evident, both in ascending and descending, that the piston cannot be moved unless the steam introduced from the boiler be of greater pressure than the atmosphere, and that it will only work with a force equal to the excess of the pressure of the steam above that of the atmosphere.

A safety valve is placed on the boiler, loaded with a weight proportionate to the strength of the steam which it is proposed to work with. This valve is frequently loaded with from 60 to 80 lbs. on the square inch. As the boilers of high pressure engines are more liable to accidents from bursting than those in which steam of a lower pressure is used, several precautions have been taken against accidents of this kind. A second safety valve is usually provided, which is not left in the power of the engine-man; so that by this means he has the power to diminish the pressure under which steam is generated, but he cannot increase it. It sometimes happens that the water in the boiler is consumed faster than it is replenished, in which case the level will fall until the boiler becomes nearly exhausted. To guard against accidents arising from this circumstance, a hole is bored in the boiler at a certain depth, and a plug of metal soldered into it with lead, or some other metal which will fuse at a temperature which would give the steam a dangerous elastic force, so that the plug would in that case drop out and make a vent for the

steam. The mercurial steam-guage, already described, is also used as an additional security against the bursting of the boiler, because the mercury will be blown out of the tube, and permit the steam to escape when the pressure is too great.

The water by which the boiler is replenished is forced in by a forcing-pump, worked by the engine itself. In order to economise the heat, this water is passed along a tube which incloses within it the pipe H, which carries off the steam which has worked the piston, so that this steam on its exit from the engine imparts a considerable portion of its heat to the water which is passing into the boiler to replace the waste occasioned by the evaporation which produced that very steam itself.

When high-pressure engines are applied to land-carriage, the cranks which are worked by the piston communicate motion to the two forewheels on which the engine runs, and by this means the alternate ascent and descent of the piston is made to turn the wheels and thereby propel the carriage. The momentum of the carriage, or its tendency to continue the motion which it has once received, in this case supersedes the use of a fly-wheel. In some cases a difficulty was found in giving motion to the carriage, owing to the wheels not taking sufficient hold upon the railway on which the carriage ran, and therefore turning without advancing. To remedy this, railways with cogs or teeth corresponding to those of the wheels were used. The cogged railways have also been superseded in some instances by common rails,

by giving six wheels to the carriage instead of four, so as to increase the friction, and distribute the pressure equally on them.

In 1804, Mr. Trevithick made a locomotive engine which was worked on railways at Merthyr Tydvil, in South Wales. It drew after it upon the rail-road as many carriages as conveyed ten tons of bar iron for a distance of nine miles, and it performed that distance without any further supply of water than what the boiler was supplied with at its departure, and travelled at the rate of five miles an hour.

(82.) Much public attention has been of late years attracted by the experiments of Mr. Perkins on steam of an unusually high degree of elasticity. Although it does not appear that he has yet succeeded to any great extent in reducing his designs to useful practical purposes, yet they evince such boldness and originality of conception, that we should not be justified in passing them without particular notice here.

The boilers of the steam-engines hitherto used serve two purposes, namely, vessels for heating the water preparatory to the production of steam, and magazines of the steam so produced for the purpose of working the engine. It occurred to Mr. Perkins, that the latter purpose might be dispensed with, and that great advantage would thus be gained by being enabled to reduce very considerably the dimensions of the boiler, to produce much more powerful vapour and to diminish in a very high ratio the

consumption of fuel. To effect this, instead of having a reservoir or store of accumulated steam ready prepared for the engine, he proposed to generate the steam only as it was required, and to permit no part of the water in the boiler to be converted into steam except just what was necessary to press the piston at each stroke.

It had been long known that the vaporization of a liquid could be resisted by mechanical pressure, and that, if so resisted, the liquid would be susceptible of receiving any temperature and yet retaining its liquid form. It was also known that upon the removal of this pressure the production of steam of an elastic force proportionate to the pressure would be the inevitable consequence. Mr. Perkins availed himself of these facts to carry into effect the design we have thus mentioned. He constructed a cylindrical vessel of copper, three inches thick, containing about eight gallons, and capable of bearing an internal pressure of 4000 lbs. on the square inch. An aperture in the end of this vessel opened into the steam-pipe by a valve loaded with thirty-five times the pressure of the atmosphere, and a safety-valve was placed on another aperture, loaded with thirty-seven times the atmospheric pressure. At another aperture a pipe was introduced into this vessel which communicated with a forcing pump, by the action of which water could be forced into it. This cylindrical vessel, which was called a generator, was completely filled with water, and was placed vertically in a furnace. The fuel in this furnace was

kept in vivid combustion by forcing air through it with bellows, a method found to be much more effectual than the ordinary draught.

The water in the generator not being permitted to expand into vapour, had its temperature raised to three, four, or five hundred degrees of the common thermometer. When this was effected a small quantity of water was forced in by means of the forcing pump, and, since water is an incompressible fluid, an equal quantity was necessarily forced out at the valve loaded with the lesser weight. This water issuing from the generator into the steam-pipe, instantly expanded, or *flashed* (as he called it) into steam of an enormous pressure, and was thus conducted to the piston, which was worked by it in the ordinary manner of a double-acting engine on Watts' principle, condensation being effected on one side, while the steam pressure was introduced on the other.

The vapour which remained uncondensed he estimated at five times the atmospheric pressure; while the steam produced by the water issuing from the generator, and pressing the piston on the other side, was equal to thirty-five times the atmospheric pressure; so that an effective impelling force was thus obtained equal to thirty times the pressure of the atmosphere, or 450 lbs. on the square inch.

The steam condensed under a pressure of five times that of the atmosphere, had a temperature of 350 degrees of the common thermometer, and at this temperature was returned into the generator by the

forcing pump, to be again circulated through the machine; thus saving a large quantity of the heat in the same manner as the hot water pump and feed pipe in Watt's engine.

The precautions used to prevent accidents from the high pressure to which the apparatus was subject, seem to have been sufficient to give every reasonable assurance of its safety. Besides that the apparatus itself was constructed to bear about 260 times the atmospheric pressure, there was, as already mentioned, a safety-valve loaded with 37 atmospheres. In addition to this, a tube entered the generator, which terminated in a copper ball, which bore with a pressure of 1000lbs. upon the square inch, or with a pressure equal to about 66 times that of the atmosphere. Another tube communicated with an indicator, an instrument which shews the strength of the pressure by means of a spiral spring, similar to the common ouncel.

It has been thought that the bursting of the boiler or of any part of the apparatus, containing water of such an extraordinary temperature, would be attended with considerable danger. This, however, Mr. Perkins states to be a mistake; for in case of such an accident the water would flow out so fast, that it would not receive the quantity of additional heat necessary to convert it into steam, and that the consequence would be, that a very small portion would assume the vaporous form; and the remainder, retaining its liquidity, would extinguish the fire. In case of the copper ball above mentioned bursting, it would tear

like paper, without any explosion or occasioning any injury. Mr. Perkins has frequently caused it to be burst for the purpose of proving this.

An engine constructed according to the plan suggested by Mr. Perkins requires only one tenth of the quantity of water requisite in the boiler of an ordinary steam-engine. By this means the danger of the bursting of the boiler is still further diminished, for the small vessel required in such an engine can always be constructed of sufficient strength. The engine first constructed by Mr. Perkins was one of ten-horse power, the cylinder being only two inches diameter and eighteen inches in length. It consumed two bushels of coal daily, and occupied a space of six feet by eight. He considered that, with the exception of the piston and cylinder, the apparatus had sufficient size and strength for three times the power.

He further proposed applying his generators to the boilers of common steam-engines, and thereby superseding the present furnaces. To effect this he proposed conducting the steam of high pressure from his generator into the common boiler, and thus heating the water in it. By such a method he considered that nine-tenths of the fuel at present used would be saved.

The patent for these improvements was granted to Mr. Perkins so long ago as the year 1823, and he has not yet been able to convince the public of the reality of the advantages which he proposes; and neither his steam-engines, nor his application of the generator to the boilers of other engines, have been brought,

forcing pump, to be again circulated ...uld not machine; thus saving a large quanti... upon its the same manner as the hot wate... att had to pipe in Watt's engine. ...eam-engines

The precautions used to prev... ...ch us caution high pressure to which the ...e claims of others. seem to have been sufficien... ...d not without some assurance of its safety. ...f steam as a substitute itself was constructed ...is manner of effecting this atmospheric pressure ...y in its detail from the air- a safety-valve load... ...of a magazine of condensed air, tion to this, a tu... ...containing water heated to such minated in a c... ...when relieved from pressure, it of 1000lbs. ...of prodigious elasticity. Balls are equal to ... ...a hopper into a gun-barrel near the Another ... ...the breech a stream of highly-elastic instrum... ...and blows the ball out of the barrel. by m... ...these projectiles are related to be fully our ... ...those of gunpowder similarly applied, and ... ...they possess the advantage of being capable ... ...discharged from the same barrel in uninter- ... succession, and for any length of time.

Upon the whole, the practical difficulty which ... to attend the use of steam in the manner proposed by Mr. Perkins, is the maintaining of the power, by keeping a sufficient quantity of water at the unusually high temperature which is requisite for his purposes. Of the actual existence or possibility of obtaining the power there can be no doubt; but unless that power can be sustained, it will avail but little, considered as a mechanical agent.

LECTURE XI.

Steam Navigation—Paddle Wheels—Mr. Oldham's New Paddle Wheels—Horses' Power.

(83.) One of the most interesting and important uses of the steam-engine is its application to nautical purposes. There are various ways in which this machine may be used in propelling a vessel through the deep; but that which is now universally adopted, is by giving, through its means, rotation to paddle wheels placed at the side of the vessel. The engine is placed in the centre of the vessel, between the wheels; and the ascent and descent of the piston is applied to work a crank, by means of which the wheels are turned, and the vessel is propelled by the action of the paddle boards on the water.

The engine works the crank through the intervention of a beam, in the manner we have already described. In the earlier nautical engines a fly-wheel was used, by the momentum of which the paddle wheels were turned, when the crank was in that position in which the engine lost its power over it (60); but those of a later period have commonly two cylinders and pistons worked by the same boiler, and two cranks upon the axle of the paddle wheels, at right

angles to each other; so that at the time when the engine loses its power over one crank it plays with its full effect on the other, and thus the fly-wheel is dispensed with. In some cases a single cylinder and piston has been used without a fly-wheel, by making the paddle-wheels themselves so heavy as to answer the purpose of a fly-wheel.

Paddle-wheels have been usually made like the common under-shot water-wheel, the paddle-boards being all directed towards the centre, as in fig. 53. This construction seems to be the best, when the paddle-boards remain fixed. The efficacy of such a wheel depends on the number of the paddle-boards, the velocity with which the wheel is turned, and the depth to which it is immersed in the water. Experiments have not yet been instituted, as far as we have been informed, which determine these circumstances satisfactorily. It is easy, however, to see that the wheel should not be immersed lower in the water than is sufficient to cover the lowest float-board A; for if more be immersed, a part of the power will be expended in lifting and depressing the water.

It is an established principle, that the action of a plane surface moving in a fluid is always perpendicular to the surface, in whatever direction it may be moved. Now, suppose the wheel immersed to the level L'L, the force of the float-board B on the water is exerted in the direction *a b*, perpendicular to it. This force, by a well known mechanical principle, *

*** The principle here alluded to is very easily understood, and may be illustrated as follows: Let a string be attached to**

is equivalent to the combined action of two forces in the directions of the sides of a parallelogram; one *a c*

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a fixed pin P, fig. 54, and passing it over a wheel fixed at M, let a weight A be suspended from it. Let another string P N be stretched from P in an horizontal direction, and a third P O in a vertical direction, and suppose a line P L drawn in the direction of the first string P M, and from any point in it, as L; draw the lines L D and L E parallel to P N and P O, so that the figure P D L E will be a parallelogram whose diagonal is P L. Passing the string P O over a wheel at O, suspend a weight B from it, which shall have the same proportion to the weight A as the line P D has to the line P L, and in like manner passing the string P N over the wheel N, suspend a weight C from it, which will have the same proportion to the weight A as the line P E has to P L. I say then, that the combined effects of the weights B and C, acting on P in the directions P O and P N will be exactly the same as the single effect of a weight equal to A, acting in the direction P L. To prove this, it is only necessary to shew that the weight A exactly counteracts the effects of the weights B and C; for since it is evident it would also exactly counteract the effect of an equal weight in the direction P L, it follows that the effect of a weight A acting in the direction P L would be exactly the same as the combined effects of the weights B and C.

To prove that this is the case, let the ends of the three strings be knotted together at P, and let the pin which secures their ends be removed, so as to leave the knot which unites the strings perfectly free. It will be found that the knot will remain at rest in the position in which it was originally placed, and that if it be drawn from this position it will return to it, and will rest in no other position whatever.

Hence we may assume, that whenever there is found a force acting in any direction, that force may be considered equivalent to two other forces, one horizontal and the other vertical.

vertical, and the other *a d* horizontal. The horizontal element *a d* is effective in propelling, but the vertical part *a c* has a lifting effect on the water, and is therefore lost. In like manner, the force of the paddle-board C is resolved into two, one *e g* vertical, and the other *e h* horizontal, the latter of which only propels. The forces of the corresponding paddles B′ C′, on the other side of the lowest paddle, being similarly circumstanced, only having a descending motion instead of an ascending one, the elements *a′ c′*, *e′ g′*, of the forces which act vertically, will be directed downwards, and will depress the water. These vertical elements of the forces on both sides of the lowest paddle-board have no effect whatever in impelling the vessel, and are therefore so much force expended without any useful effect.

If the wheel be supposed to be immersed below its axle to the level L′ *l*, owing to its occasionally dipping in the water from the roughness of the sea, the action of the horizontal paddles D′ D is totally lost, their whole force being expended in lifting or depressing; and the actions of the paddles E′ E above these being resolved, like the others, into vertical and horizontal elements, the horizontal elements will have a retarding effect, as is indicated by the direction of the arrows.

It is evident, from inspecting the position of the arrows, which indicate the directions of the horizontal elements of the forces, and also from the length of the sides of the parallelograms, which indicate the magnitudes of these elements, that the more deeply such a wheel as this is immersed,

the more force will be lost, in proportion to the force expended. Such a wheel should not, therefore, be immersed to a greater depth than that of the lowest paddle.

Various contrivances have been suggested to avoid the expenditure of force in lifting and depressing the water, and also to remove the back action already mentioned; in other words, it has been attempted to make the paddle-boards *feather* themselves in rising from the water.

In one instance a mechanism was contrived, which, by making each paddle revolve on its axis in the same time as the wheel itself, and in an opposite direction, the paddles were always kept in the vertical position, as in fig. 55. In such a wheel, the back action of the paddles above the axle is increased by exactly as much as the propelling power of those which are below it. Besides this, other practical objections were found to apply to it. In a rough sea, such a wheel presented a surface to the surge which formed a solid breakwater, and produced a liability to fracture and derangement. A wheel of this kind would seem, however, to be well suited to river work.

(84.) Mr. Oldham, engineer to the Bank of Ireland, has lately constructed a paddle-wheel, in which there is no back action, and for which a patent has been obtained. In this wheel the paddle-boards are made, by a most ingenious and simple mechanism, to revolve on axes independent of that of the wheel, and each paddle-board re-

volves once on its axis, while the wheel revolves twice; the paddle-boards revolving in a direction different from that of the wheel. The consequence of the combination of these two motions is, that the edge of every paddle-board is always presented to the highest point of the wheel, as represented in fig. 56. The entire action of each board perpendicular to its surface being resolved into two actions, as in the former case, one horizontal and the other vertical, the proportions, quantities, and directions of these actions will be seen at once, by observing the sides of the several parallelograms in the figure, and the directions of the arrows. One peculiarity which this presents, and in which it differs most strikingly from other wheels, is, that *all* the horizontal arrows point in the same direction, indicating that all the horizontal elements of the forces of the boards act in the same direction, and that they can, therefore, be made to propel, without any back action whatever. It will also be observed that the vertical elements, which on the one side of the vertical diameter *lift*, and on the other side *depress*, are much smaller in proportion to the whole force than in the common wheels, and therefore the force expended without useful effect is much less in proportion to the whole force in these than in the common wheels.

A wheel of this kind, having no back action, might be totally immersed, and would still continue to propel. In consequence of the diminution of the lifting and depressing effects, or what is the same, of the degree of the *feathering* principle

with which it is endued, its motion through the water is smooth, and attended with but little agitation, and is therefore the more effectual as an impellent power. I have instituted experiments with this wheel, compared with the common wheel, and find the results to coincide most satisfactorily with those which I have deduced from mathematical calculation.

Wheels of this description do not seem to be liable to the same objections as the common wheels, in their application to canal work; for the extreme smoothness with which they move through the water is such, that no agitation could be produced by them which would be calculated to injure the banks; an effect which has hitherto impeded the application of steam-boats to any great extent in inland navigation. The wheel might even be totally immersed, in which case they might be under the vessel, and in the middle of the canal.

Owing to the facilities offered by the great lakes and rivers, steam-navigation was introduced into America at an earlier period than in England. The first steam-boat which we learn to have been permanently established, plied between New York and Albany, on the river Hudson. The curious effects of her first appearance are thus described, in a quotation made by Mr. Partington from an American work :—

" She had the most terrific appearance, from other vessels which were navigating the river, when she was making her passage. The first steam-boats, as others yet do, used dry pine wood for fuel, which sends forth a column of ignited vapor, many feet

above the flue, and whenever the fire is stirred, a galaxy of sparks flies off, and in the night have a very brilliant and beautiful appearance. This uncommon light first attracted the attention of the crews of other vessels. Notwithstanding the wind and tide were adverse to its approach, they saw with astonishment that it was rapidly coming towards them; and when it came so near as that the noise of the machinery and paddles was heard, the crews in some instances shrunk beneath the decks from the terrific sight, and left their vessels to go on shore; while others prostrated themselves, and besought Providence to protect them from the approaches of the horrible monster which was marching on the tide, and lighting its path by the fires which it vomited.

In 1812, steam-vessels were first introduced upon the Clyde, and since that period steam-navigation has rapidly extended, so that at present there is scarcely a part of the civilized globe to which it has not found its way. The Atlantic and Pacific Oceans have been traversed by its powers, and if the prolific results of human invention should suggest means of diminishing the consumption of fuel, or obtaining a supply of heat from materials sufficiently small and light, it would be hard to assign limits to the powers of this most wonderful agent.

(85.) The conventional method of expressing the power of an engine with reference to that of horses, was first adopted by Savery, and arose, naturally enough, from the circumstance of the work proposed to be executed by steam-engines, having been previ-

ously done by horse-mills. It was therefore customary to say that this or that steam-engine would be equivalent to a mill worked by ten or twenty, or any given number of horses. The standard was one with which those for whose use steam-engines were intended were perfectly acquainted, and no method of expressing the power of the machine could have come so home to their familiar notions, nor have been so perfectly appropriate and fair.

A horse's power is, however, to a certain degree, an indefinite standard, since horses vary in strength, one being able to do double the work of another. While, therefore, it would have been very inexpedient to have totally abandoned this universally received and sufficiently well understood standard, it became necessary, as the manufacture of steam-engines became more general, to give the standard a more fixed and definite meaning. For this purpose, a horse's power is estimated at so many pounds of water, raised through the height of one foot per minute, the animal being supposed to work for eight hours daily. As to the number of pounds to be thus assigned to a horse's power, engineers have differed. Smeaton estimates the average power of a horse at 22,916lbs. raised one foot per minute for eight hours a day. Desaguliers makes it 27,500. Messrs. Boulton and Watt caused experiments to be made with the strong horses used in the breweries in London, and from the result of these they assigned 32,000lbs. as the proper value of a horse's power. This, however, is considered rather above the fair average, but in the estimation of the power of engines, this error ope-

rates against the manufacturer and in favour of the purchaser, as it rather underrates the power of the engine.

In estimating the power of an engine, compared with horses, it is supposed only to work for the same time, i. e. eight hours daily; whereas the engine has the advantage of being capable of working for twenty-four hours per day. If this were taken into account, the power of an engine would be three times what it is now denominated.

THE END.

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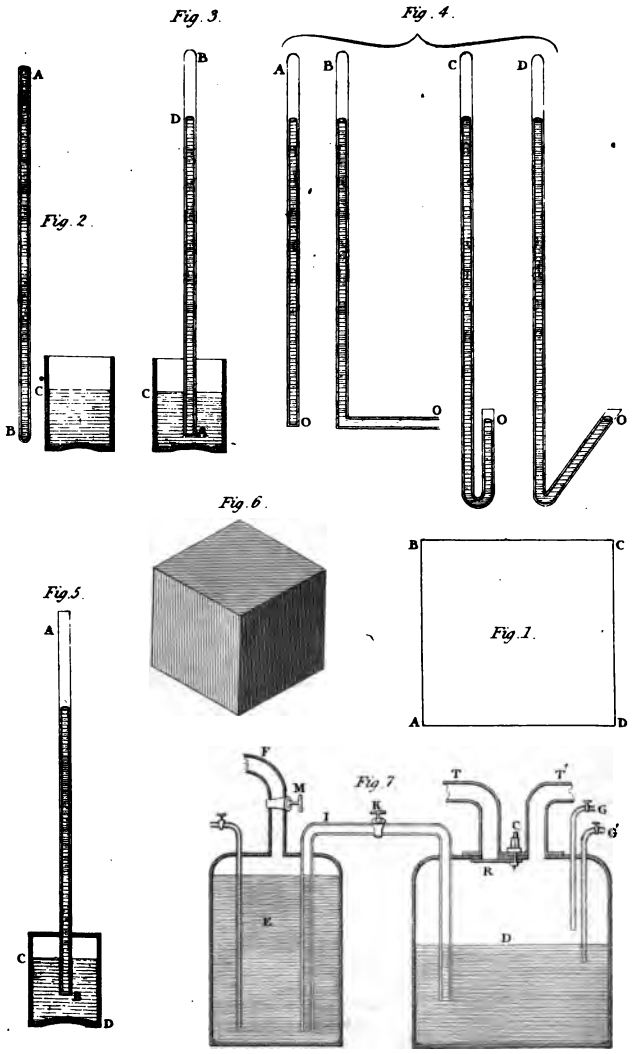

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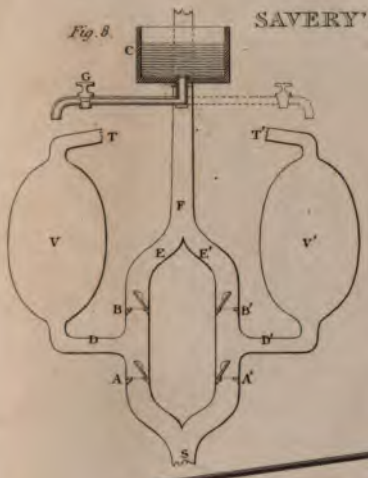
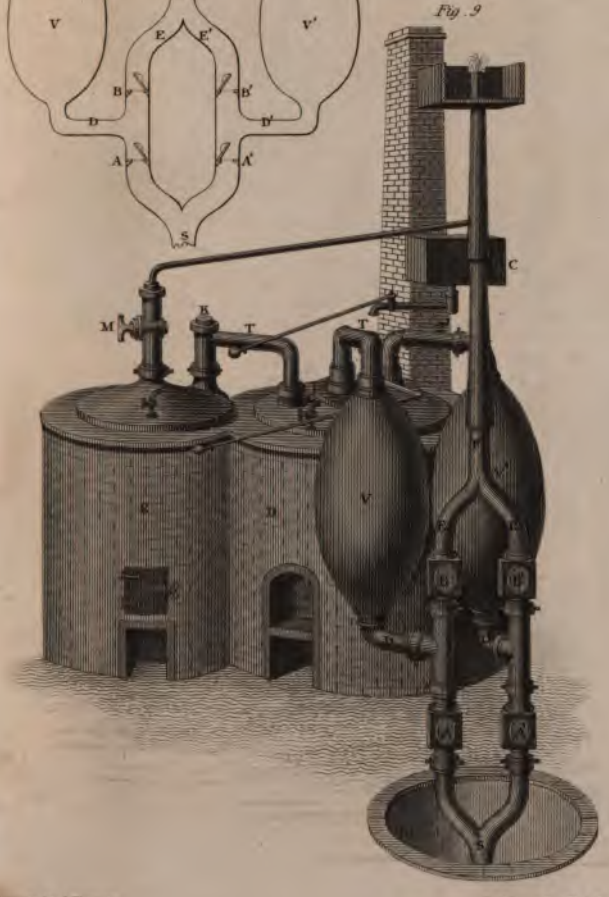
SAVERY'S STEAM ENGINE.





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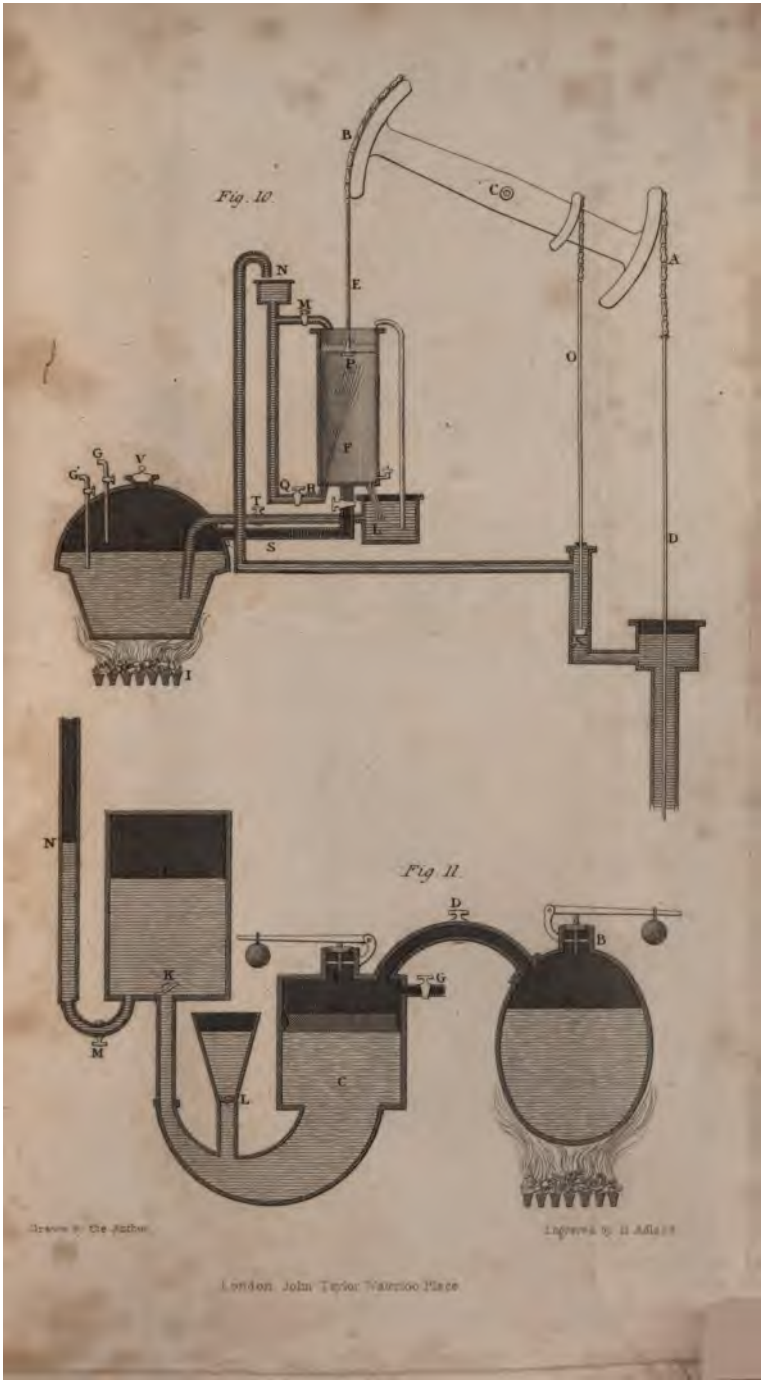

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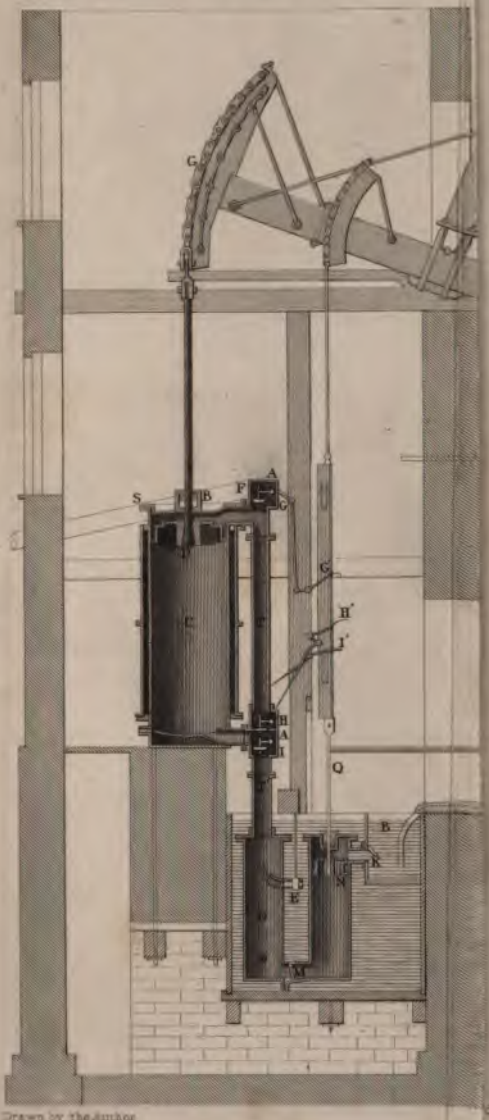

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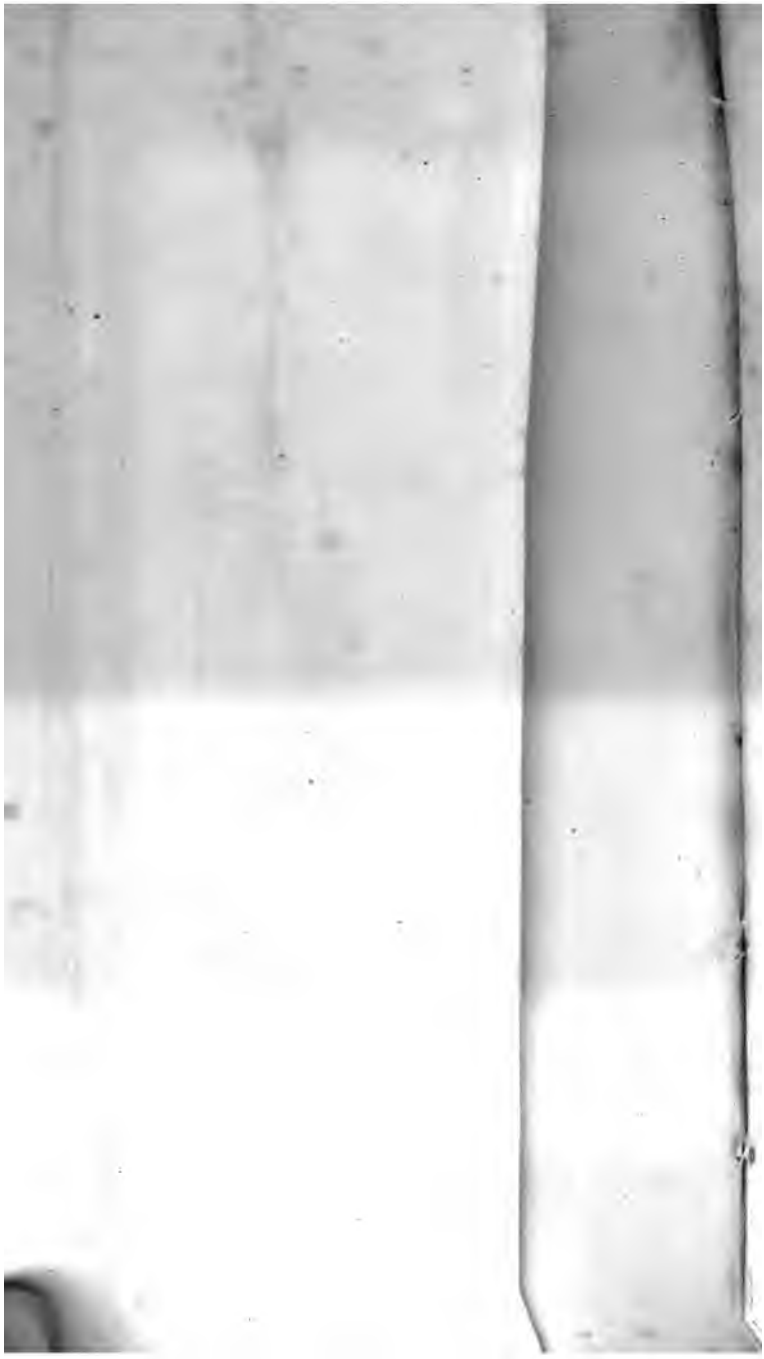

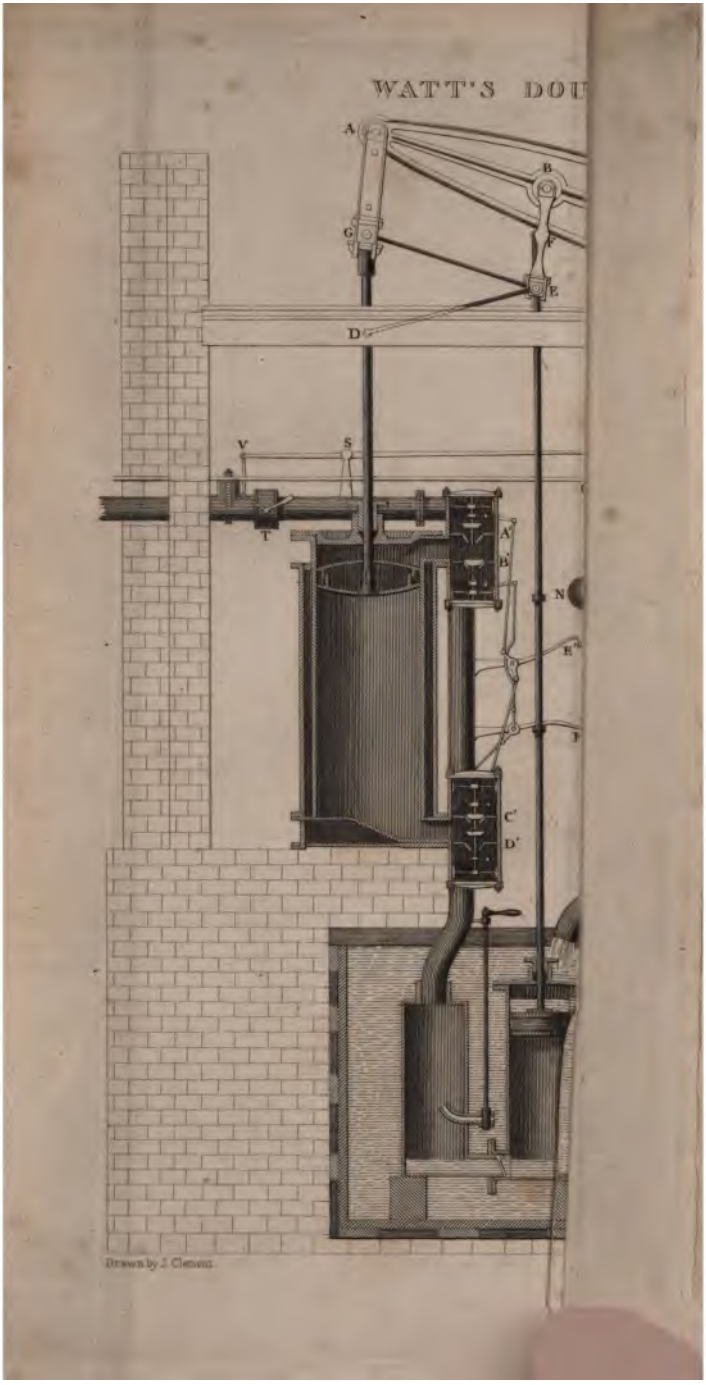
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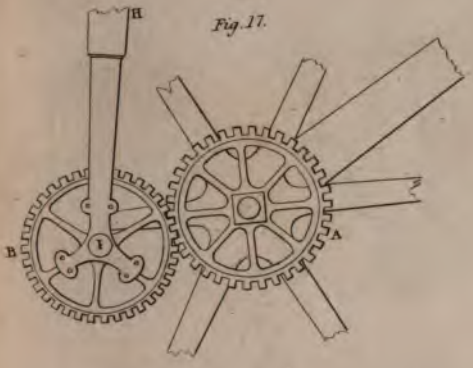

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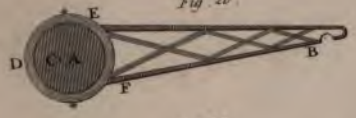

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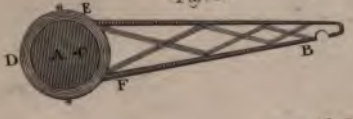

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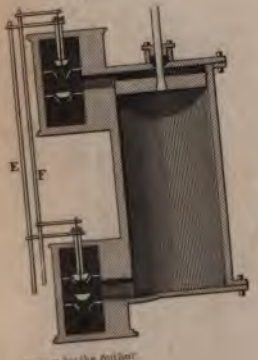

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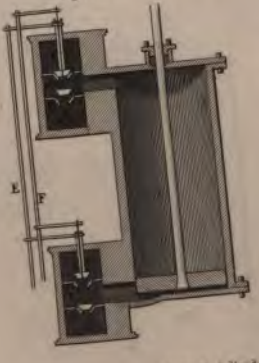

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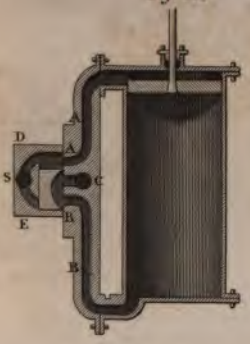

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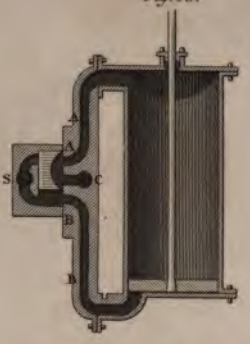

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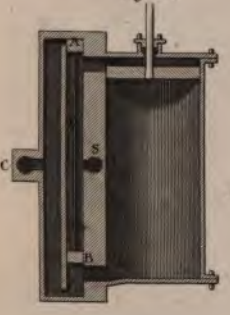

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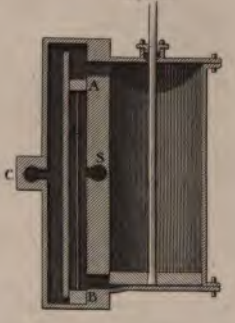

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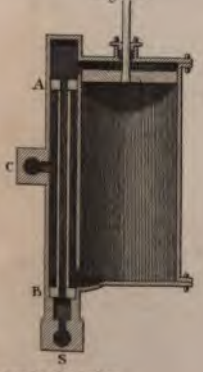

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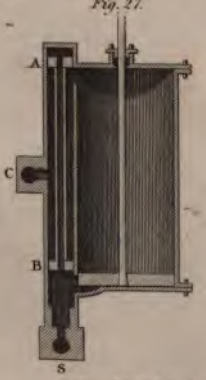

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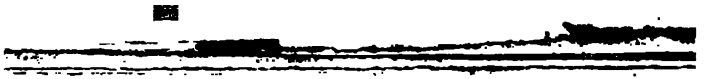

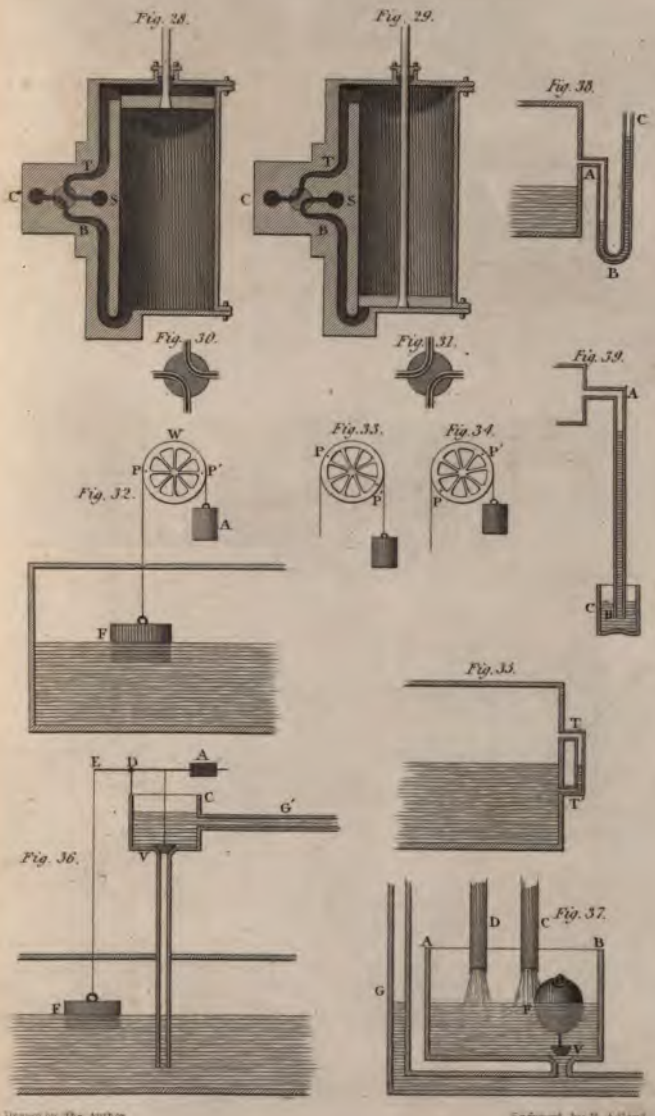

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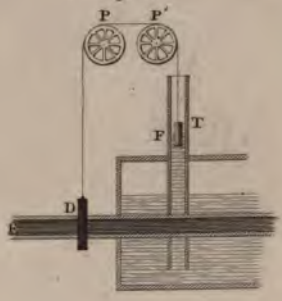

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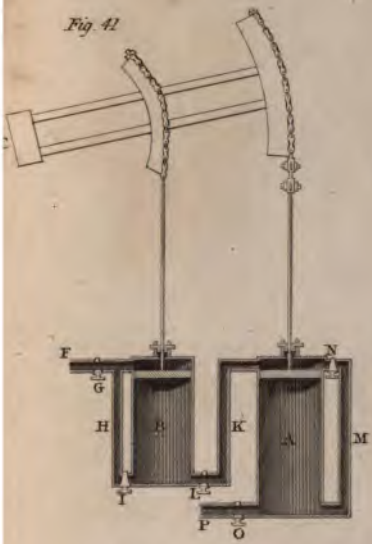

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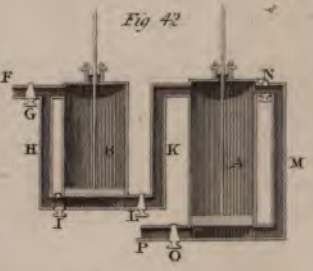

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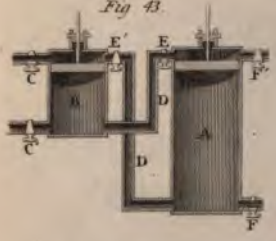

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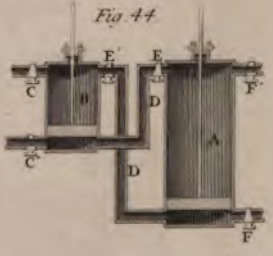

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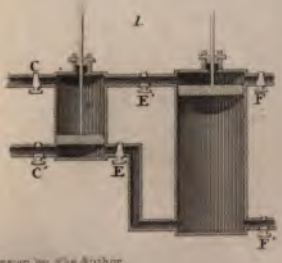

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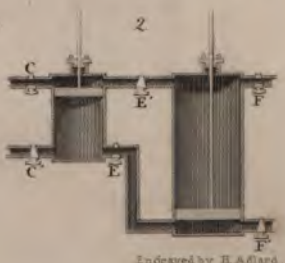

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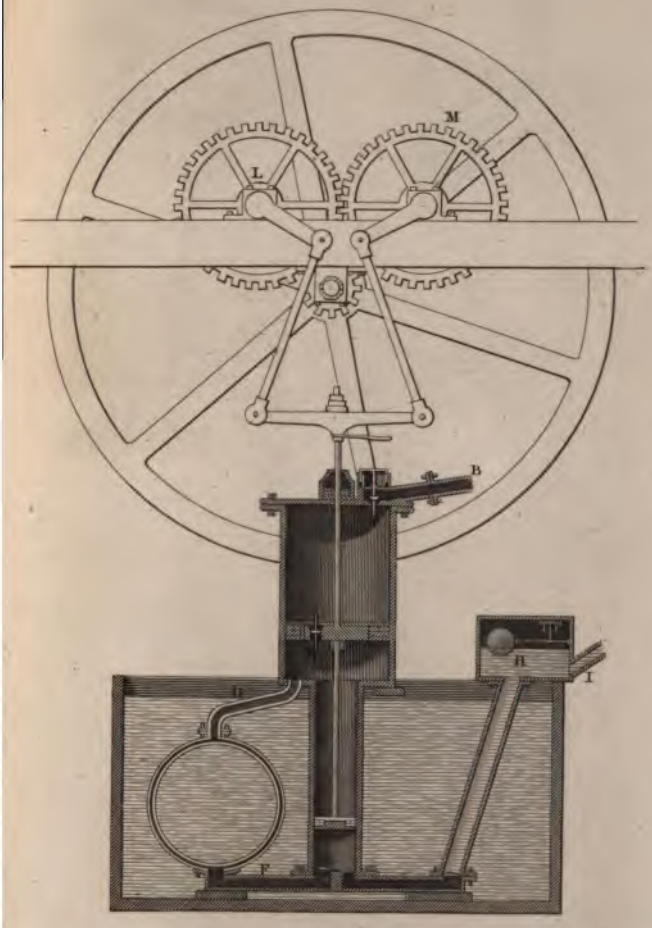

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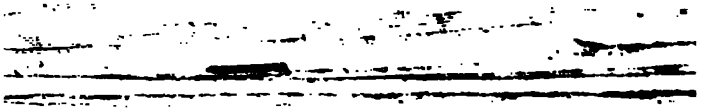

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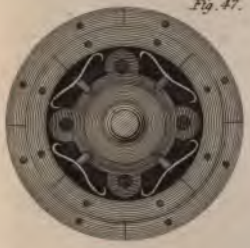

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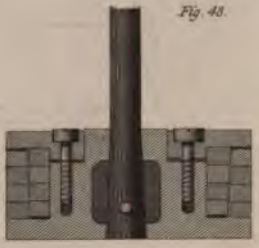

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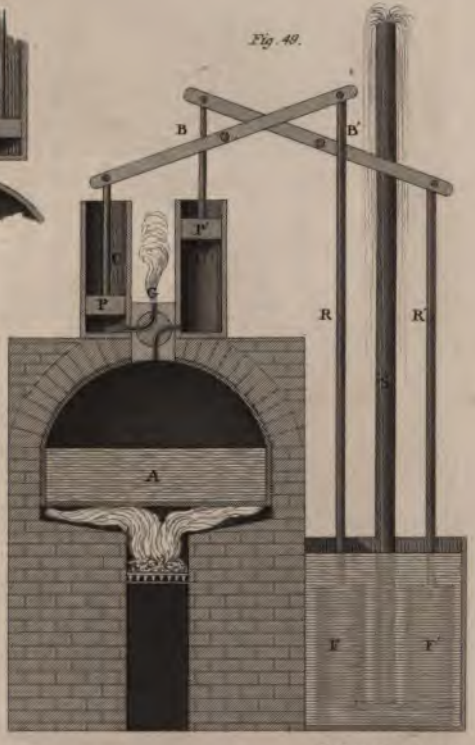

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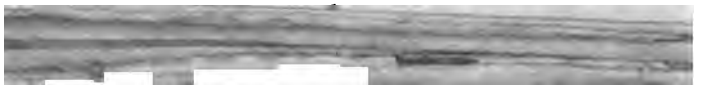

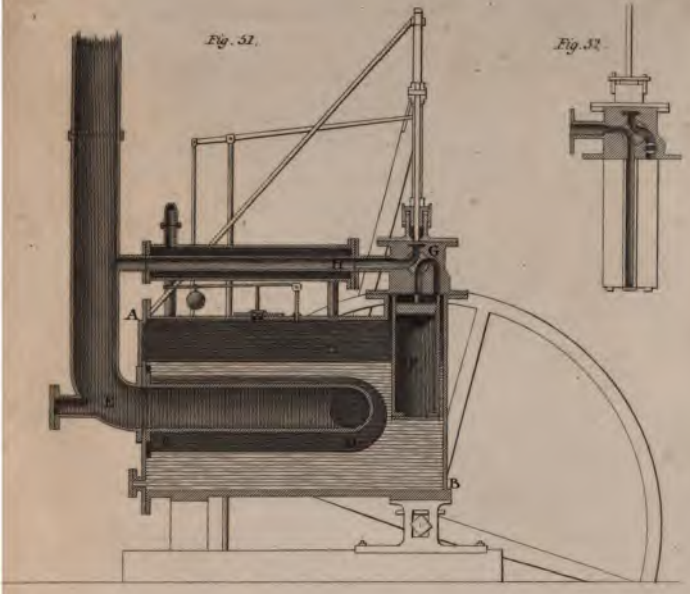

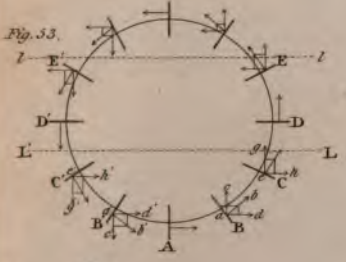

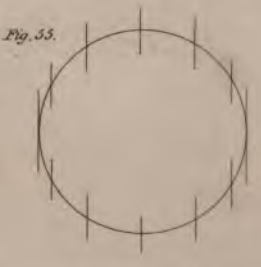

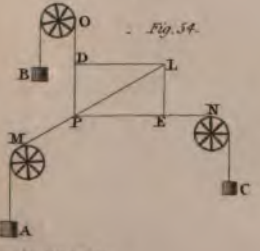

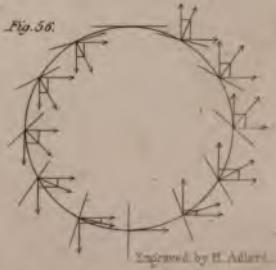

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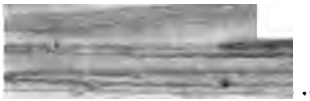

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